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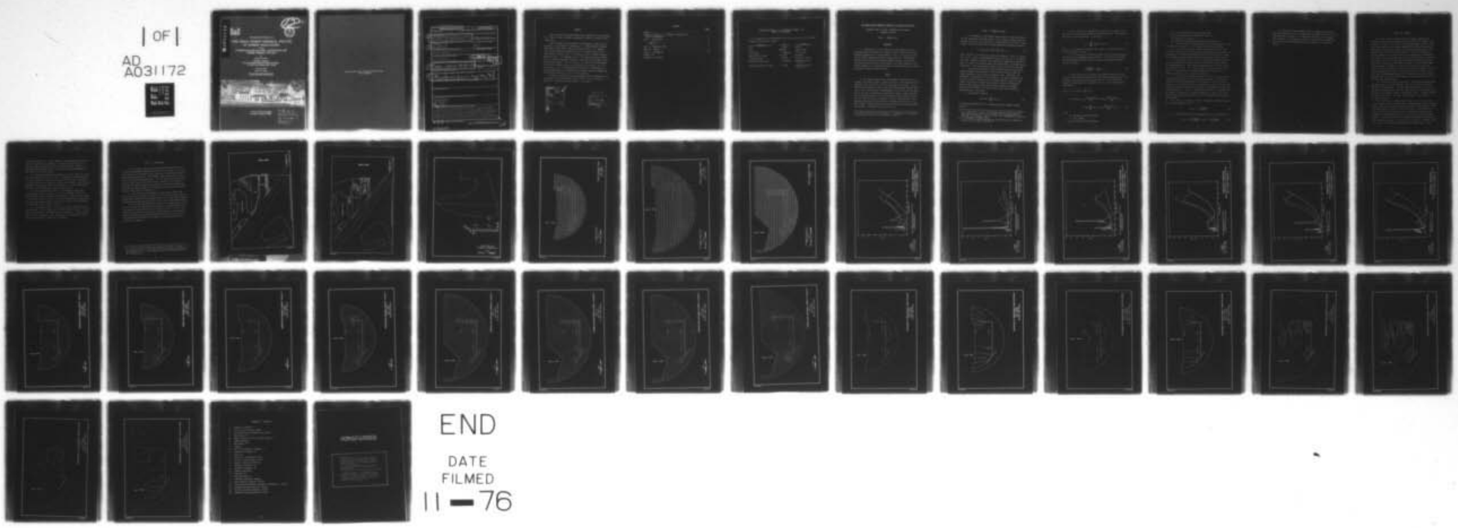

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LONG BEACH HARBOR NUMERICAL ANALYSIS OF HARBOR OSCILLATIONS

Report 2

ALTERNATE PLANS FOR PIER J COMPLETION AND TANKER TERMINAL PROJECT

by

James R. Houston

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U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1976

Report 2 of a Series

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A hybrid finite element numerical model was used to calculate harbor resonance for three alternate plans for the Pier J completion and tanker terminal project of Long Beach Harbor. The numerical model calculates harbor oscillation for harbors of arbitrary shape and variable depth. Three finite element grids which covered areas only in the immediate vicinity of the breakwater-protected tanker terminal area were used to calculate the response of this area to incident waves with periods from 30 sec to approximately 6 min.

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PREFACE

The investigation reported herein was authorized by the Long Beach Port Authority under a contract, Agreement No. WES 76-4, dated 12 September 1975.

The investigation was conducted from September to March 1976 by personnel of the Hydraulics Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, Dr. R. W. Whalin, Chief of the Wave Dynamics Division, Mr. D. D. Davidson, Chief of the Wave Research Branch, and Mr. C. E. Chatham, Chief of the Harbor Wave Action Branch. Mr. J. R. Houston, Research Physicist, conducted the investigation and prepared this report. Mr. R. R. Bottin, Jr. aided in the development of the finite element grids and the plotting of the data. Drs. H. S. Chen and C. C. Mei of the Massachusetts Institute of Technology provided documentation of the hybrid finite element computer program they developed and materials to aid in its utilization.

Directors of WES during the investigation and the preparation and publication of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
acres	4046.856	square metres
cubic yards	0.7645549	cubic metres
tons (2000 lb, mass)	907.1847	kilograms
feet per second	0.3048	metres per second
square feet per second	0.09290304	square metres per second
feet per second per second	0.3048	metres per second per second

LONG BEACH HARBOR NUMERICAL ANALYSIS OF HARBOR OSCILLATIONS

ALTERNATE PLANS FOR PIER J COMPLETION AND TANKER TERMINAL PROJECT

PART I: INTRODUCTION

Objective

1. The objective of this study was to investigate by use of a numerical model the response to long-period wave excitation of three proposed alternatives for modifications to Pier J in Long Beach Harbor for oil tanker berthing and general cargo facilities. Wave-height amplification factors and normalized maximum current velocities were plotted versus wave period at the proposed oil tanker terminals to ascertain whether or not significant harbor oscillation might occur which would pose problems to ship berthing.

Scope

2. Two tanker terminal basin configurations (plans) were considered in the study; plan 1 is shown in Plate 1. Both 300- and 600-ft* openings at the east end of the 62-ft deep basin were tested. Plan 2 (Plate 2) was similar to plan 1 except that the proposed landfill addition to Pier J was reduced to approximately 50 acres with an open-water area to the east for mooring two 250,000-dwt tankers. Waves incident from a direction normal to the main breakwater face with periods from 30 sec to 300-340 sec were considered for both configurations. Wave amplitude and current velocities were calculated every 5 sec for the period range. Resonant peaks also were defined by considering incident wave periods in increments as low as 0.25 sec.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

PART II: NUMERICAL MODEL

3. The response of the tanker terminal basin to long wave excitation was determined by using a hybrid finite element numerical model developed recently by Chen and Mei* at the Massachusetts Institute of Technology. The model solves the following generalized Helmholtz equation:

$$\nabla \cdot \left[h(x,y)\nabla\phi(x,y)\right] + \frac{w^2}{g}\phi(x,y) = 0 \qquad (1)$$

where $\phi(x,y)$** is the velocity potential defined by $u(x,y) = -\nabla d(x,y)$, with $u(x,y)$ being a two-dimensional velocity vector and w an angular frequency. Equation 1 governs small amplitude undamped oscillations of water in a basin of arbitrary shape and variable depth forced by periodic long waves. It has been further assumed that the flow is irrotational.

4. The boundary condition along the shoreline and along the detached breakwater surrounding the three proposed berths is that the normal component of the velocity be equal to zero. Therefore, the breakwater is considered as a solid barrier. No special boundary conditions are made to account for the storage tankers in plan 2 or any vessels utilizing the tanker terminal basin, since for long-period waves of small amplitude ship heave equals incident wave height. Therefore, the vessels do not significantly alter the oscillation characteristics of the basin.

5. The Helmholtz equation:

$$\nabla^2\phi(x,y) + \frac{w^2}{gh}\phi(x,y) = 0 \qquad (2)$$

is the governing equation for a constant-depth ocean region outside the basin.

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* H. S. Chen and C. C. Mei, "Oscillations and Wave Forces in an Offshore Harbor (Applications of the Hybrid Finite Element Method to Water-Wave Scattering)," Report No. 190, 1974, Massachusetts Institute of Technology, Cambridge, Mass.

** For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix A).

6. For a harbor in a semi-infinite ocean with a straight coastline there is an incident, reflected, and scattered wave. The scattered wave has a velocity potential ϕ_s given by

$$\phi_s = \sum_{n=0}^{\infty} \alpha_n H_n(kr) \cos n\theta \qquad (3)$$

where α_n are unknown coefficients and $H_n(kr)$ are Hankel functions of the first kind of order n .

7. ϕ_s satisfies the radiation condition that the scattered wave must behave as an outgoing wave at infinity. This condition is known as the Sommerfeld radiation condition and may be expressed mathematically as follows:

$$\lim_{r\to\infty} \sqrt{r}\left(\frac{\partial}{\partial r} - ik\right) \phi_s = 0 \qquad (4)$$

8. Chen and Mei used a calculus of variations approach and obtained a Euler-Lagrange formulation of the boundary value problem. The following functional with the property that it is stationary with respect to arbitrary first variations of $\phi(x,y)$ was constructed by Chen and Mei:

$$F(\phi) = \iint 1/2 \{h(\nabla\phi)^2 - \frac{w^2}{g} \phi^2\} \, dA$$

$$+ 1/2 \S\{h(\phi_R - \phi_I) \frac{\partial(\phi_R - \phi_I)\}}{\partial n_a} da - \S\{h\phi_a \frac{\partial(\phi_R - \phi_I)\}}{\partial n_a} da$$

$$- \S\{h\phi_a \frac{\partial\phi_I}{\partial n_a}\} da + \S\{h\phi_I \frac{\partial(\phi_R - \phi_I)\}}{\partial n_a} da \qquad (5)$$

where

A = the region inside the harbor

§ = line integral

ϕ_R = far field velocity potential

ϕ_I = velocity potential of the indicent wave

n_a = unit normal vector outward from region A

a = boundary of region A

ϕ_a = total velocity potential evaluated on boundary a

9. Proof was given by Chen and Mei that the stationarity of this functional is equivalent to the original boundary value problem.

10. The integral equation obtained from extremizing the functional is solved by utilizing the finite element method. This method is a technique of numerical approximation that involves dividing a domain into a number of nonoverlapping subdomains which are called elements.

11. The solution of the problem is approximated within each element by suitable interpolation functions in terms of a finite number of unknown parameters. These unknown parameters are the values of the field variable $\phi(x,y)$ at a finite number of points which are called nodes. The relations for individual elements are combined into a system of equations for all unknown parameters.

12. In the region outside the basin, the velocity potentials are solved analytically in terms of unknown coefficients. The region is considered a single element with an "interpolation function" given by Equation 3. The infinite series is terminated at some finite value such that the addition of further terms does not significantly influence the calculated values of $\phi(x,y)$. The resulting equation is combined with the system of equations for unknown parameters at nodal points within the basin and this complete system is solved using Gaussian elimination matrix methods.

13. $\eta(x,y)$ is related to $\phi(x,y)$ through the linearized dynamic free surface boundary condition

$$\eta(x,y) = -\frac{1}{g}\frac{\partial\phi(x,y)}{\partial t} \tag{6}$$

14. The horizontal velocity components have the following form:

$$u(x,y) = -\frac{g}{w}\frac{\partial\eta(x,y)}{\partial x};\; v(x,y) = -\frac{g}{w}\frac{\partial\eta(x,y)}{\partial y} \tag{7}$$

15. The hybrid finite element method (so named by Chen and Mei because the method involves the combination of analytical and finite element numerical solutions) is a steady-state solution of the boundary value problem. The response of a harbor to an arbitrary forcing function can be easily determined within the framework of a linearized theory.

PART III: RESULTS

16. Plate 3 shows the locations of the tanker terminals and Plates 4-6 show the finite element grids for STFP 2 (300), STFP 2 (600), and STFP 3. Plates 7-9 are plots of normalized maximum current velocity versus wave period at each tanker terminal for the three modifications. The current velocity multiplied by the incident wave amplitude in feet gives velocity in units of feet per second. The velocities have no vertical component or variation since only long waves are considered in this study. Also, the maximum velocity over one wave period is plotted. Plates 10-12 are plots of the wave-height amplification factor versus wave period in seconds at each tanker terminal. The wave-height amplification factor is defined at a point inside the basin as the wave height at the point divided by twice the incident wave height. This definition of amplification factor is traditional and is a result of the fact that the standing wave height for a straight coast with no harbor would be twice the incident wave height due to the superposition of the incident and reflected waves.

17. Plan STFP 2 (300) and plan STFP 2 (600) have normalized maximum current velocity (NMCV) resonant peaks of 57 and 250 sec and 57.5 and 260 sec, respectively. The NMCV patterns in Plates 13 and 15 for the peaks of approximately 1 min are very similar for the two plans with the velocities somewhat larger for plan STFP 2 (600). The NMCV patterns in Plates 14 and 16 for the peaks of approximately 4-1/2 min are virtually identical.

18. Plan STFP 3 has NMCV resonant peaks of 55, 55.5, 106, and 350 sec (Plates 17-20). The NMCV peak of approximately 1 min is substantially larger than similar peaks for plans STFP 2 (300) and STFP 2 (600). The NMCV patterns in Plates 17 and 18 are similar to the patterns in Plates 13 and 14 with high velocities occurring near corners of the breakwater. Large velocities also occur in the area of the storage tankers. The 106-sec NMCV peak is substantially larger for plan STFP 3 than the other two plans. Velocities are very large at terminals 2 and 3 as a result of the antinode forming in the inside corner of the

breakwater (see Plate 27 of the contours of wave-height amplification). The 350-sec NMCV peak at terminal 1 is similar in magnitude to the 4-1/2-min peaks at terminal 1 for the other two plans. However, the NMCV peaks at terminals 2 and 3 are less than corresponding peaks of plans STFP (300) and STFP (600).

19. Wave-height amplification factors are quite similar for plans STFP (300) and STFP (600) Plates 10-12. Contours of wave-height amplification presented in Plates 21-24 are also very similar. Antinodes for the 1-min peak are located at the two inside corners of the detached breakwater and along the shore near terminal 3. A single antinode in the center of the basin forms for the 4-1/2-min peak.

20. The 1-min peak for STFP 3 is substantially larger than corresponding peaks for the other two plans. Antinodes form in the inside corners of the breakwater, near terminal 3, and along the corner of the landfill Plates 25 and 26. Contours of wave-height amplification for the 350-sec peak of STFP 3 (Plate 28) are similar to the contours for plans STFP 2 (300) and STFP 2 (600).

21. In summary, larger 1- and 2-min resonant oscillations occur for plan STFP 3 than for plans STFP 2 (300) and STFP 2 (600). The 4- to 6-min oscillations are somewhat larger for plans STFP 2 (300) and STFP 2 (600) than for plan STFP 3. The oscillation characteristics of plans STFP 2 (300) and STFP 2 (600) are very similar.

PART IV: CONCLUSIONS

22. The resonant peaks of the normalized maximum current velocity and the wave-height amplification factor do not appear to preclude safe berthing at the terminal areas, given proper mooring practices and adequate mooring equipment. The resonant response peaks for incident waves with periods of approximately 1 to 2 min are significantly larger for plan STFP 3 than for the STFP 2 plans. Whether or not incident waves in this period range excite significant ship motion depends upon ship characteristics (length, width, and draft) and mooring conditions (type of lines, amount of slack, etc.).

23. The incident wave spectrum and ship response versus wave period curves must be known in addition to the harbor response curves of Plates 7-12 to definitively determine whether or not ship surge problems resulting from harbor resonance will occur in the tanker terminal basin.

24. Until detailed information on moored ship response as a function of incident wave amplitude and frequency is obtained, definitive conclusions on the precise amount of ship motion cannot be made. However, the oscillations of the tanker terminal basin are significantly smaller than typical oscillations noted throughout the Los Angeles and Long Beach Harbors complex in the numerical study performed for the entire harbor complex.*

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* J. R. Houston, "Long Beach Harbor Numerical Analysis of Harbor Oscillations; Report 1, Existing Conditions and Proposed Improvements" (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

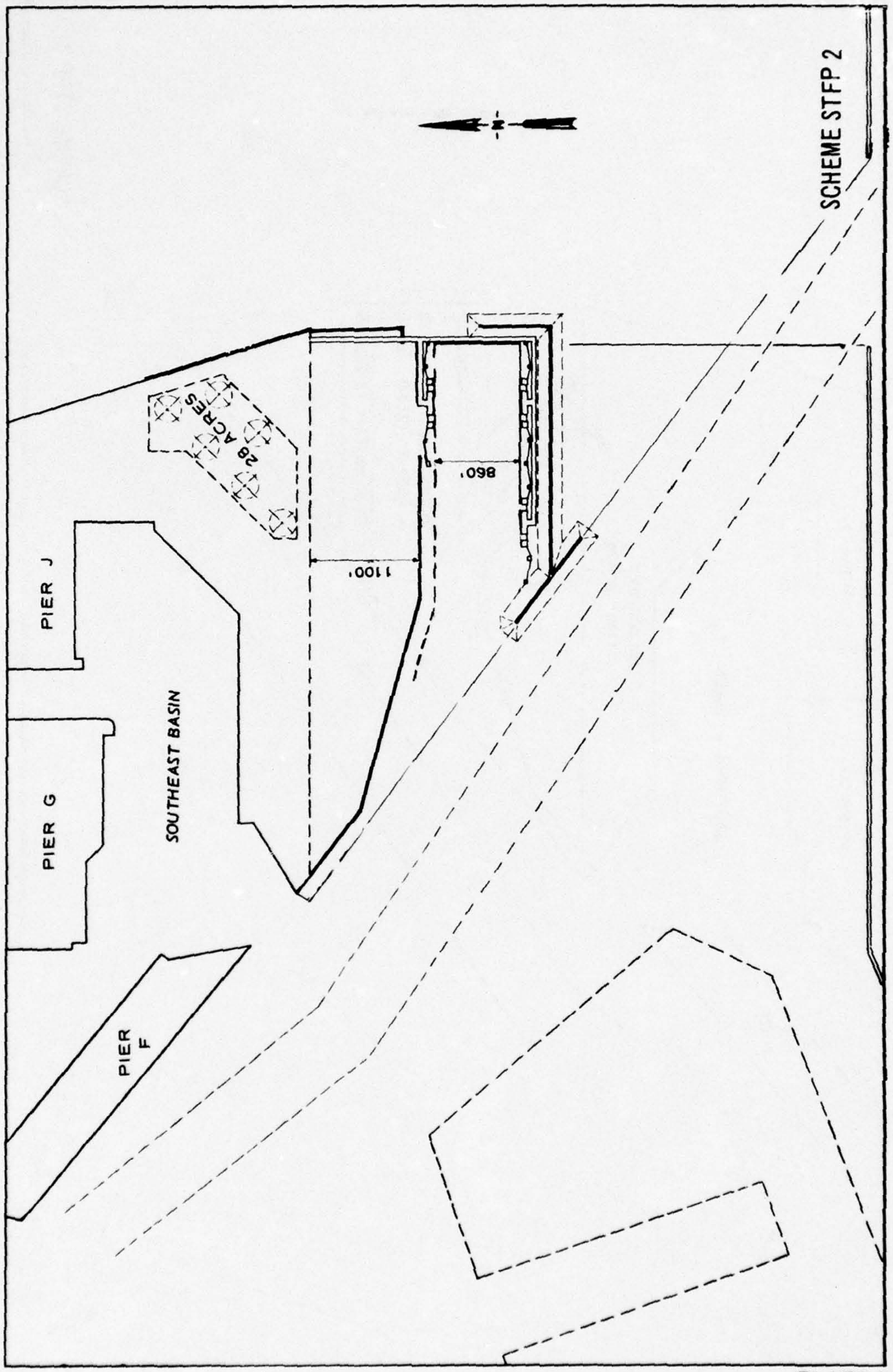
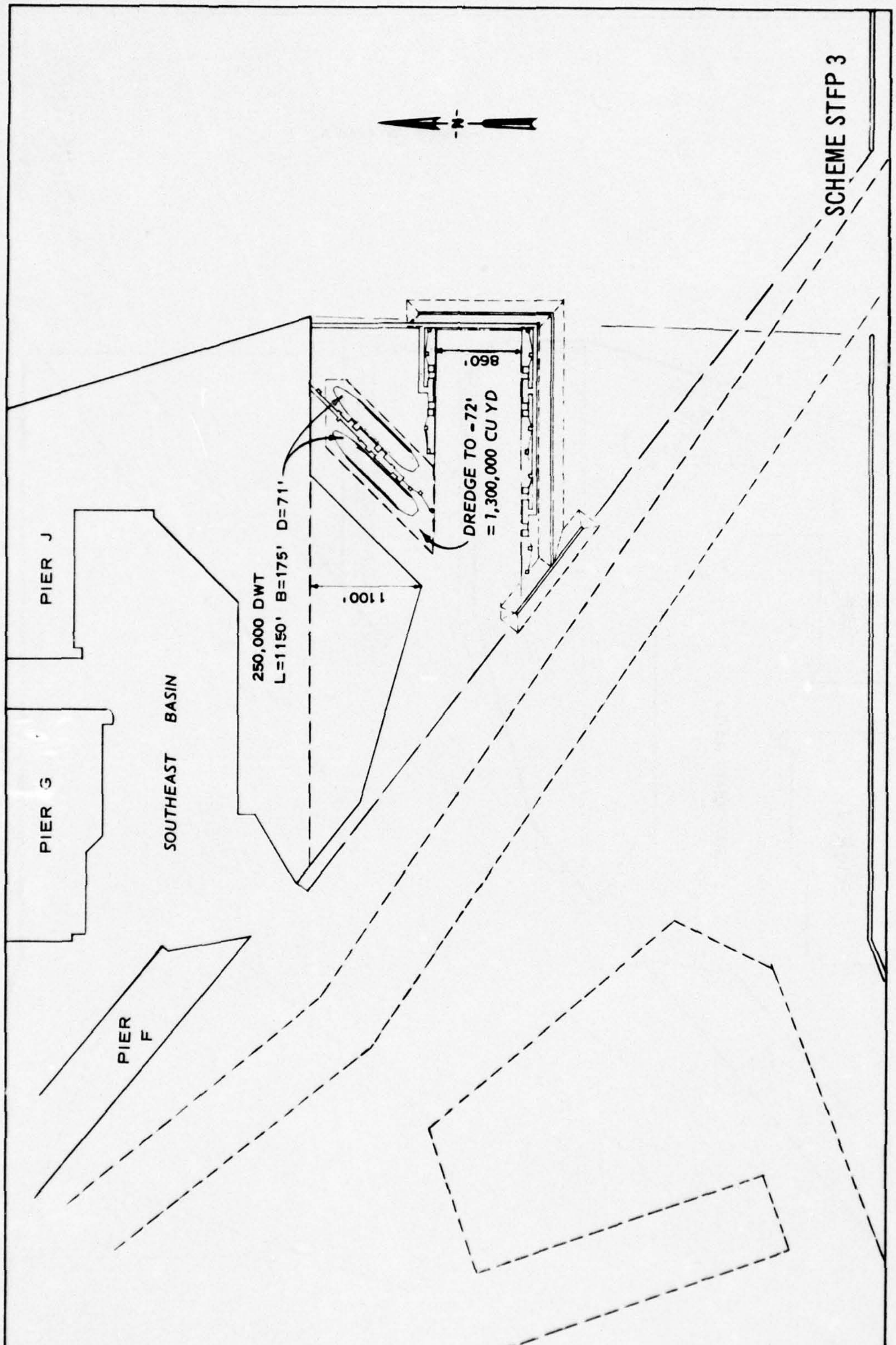
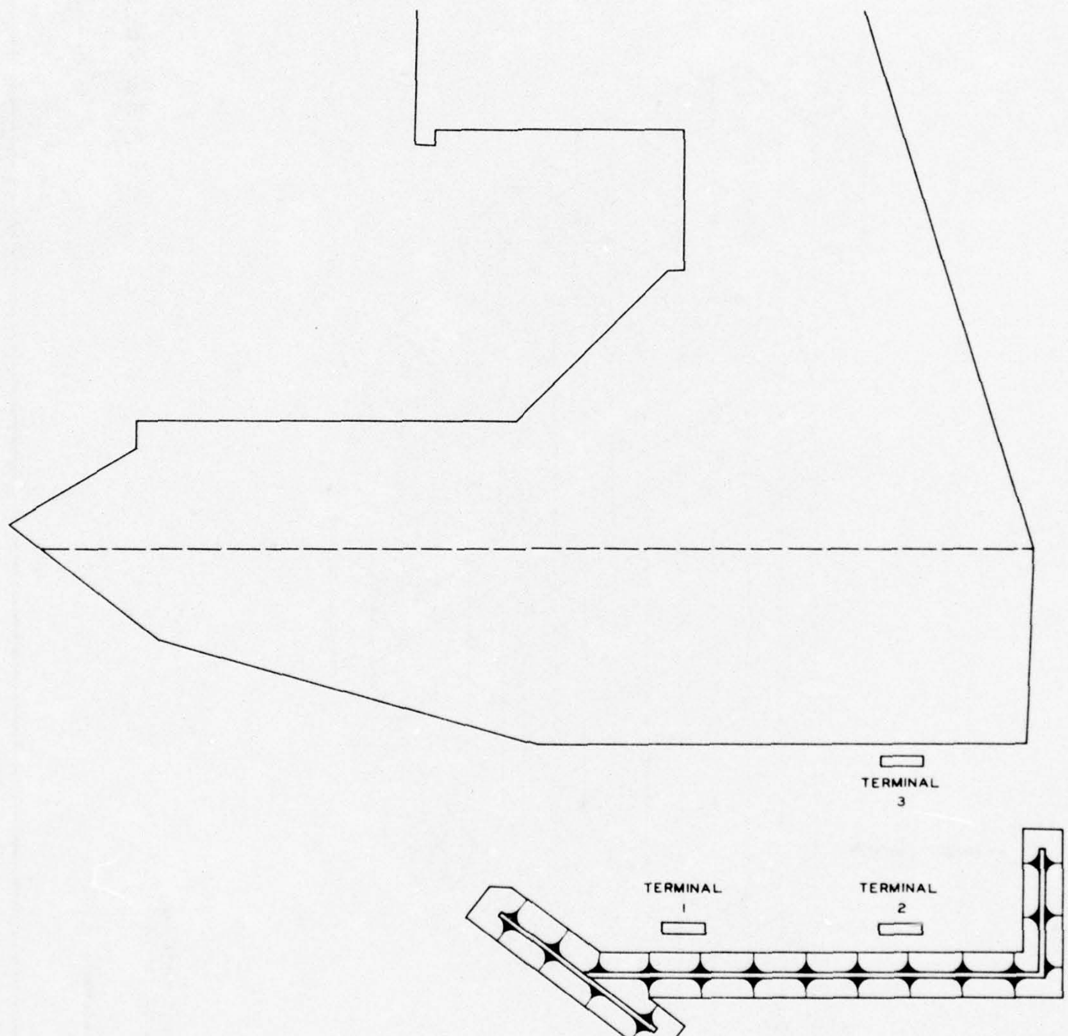

SCHEME STFP 2
N
28 ACRES
860'
1100'
PIER J
PIER G
PIER F
SOUTHEAST BASIN

PLATE 1



SCHEME STFP 3
N
PIER J
PIER G
PIER F
SOUTHEAST BASIN
250,000 DWT
L=1150' B=175' D=71'
1100'
860'
DREDGE TO -72'
= 1,300,000 CU YD

PLATE 2

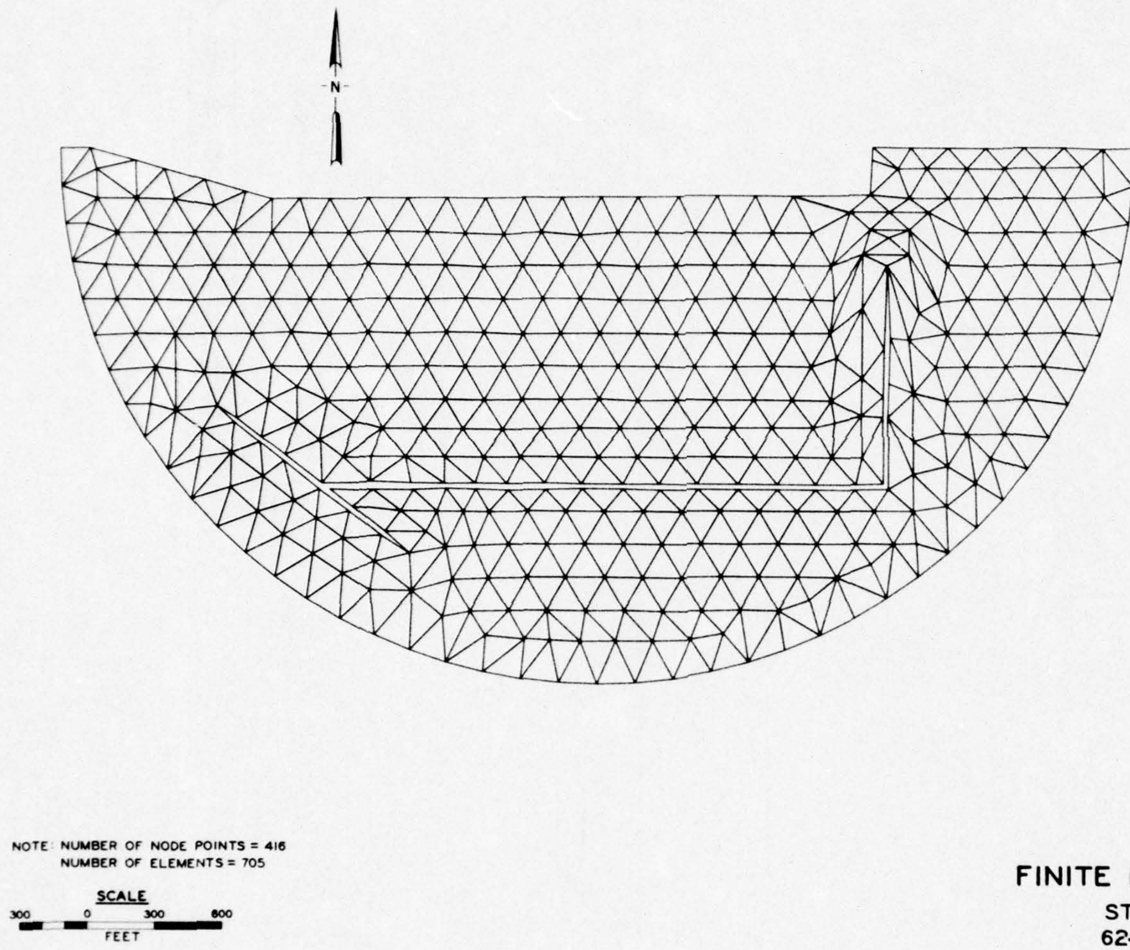


LOCATION OF
TANKER TERMINALS

SCALE

500 0 500 1000 FT

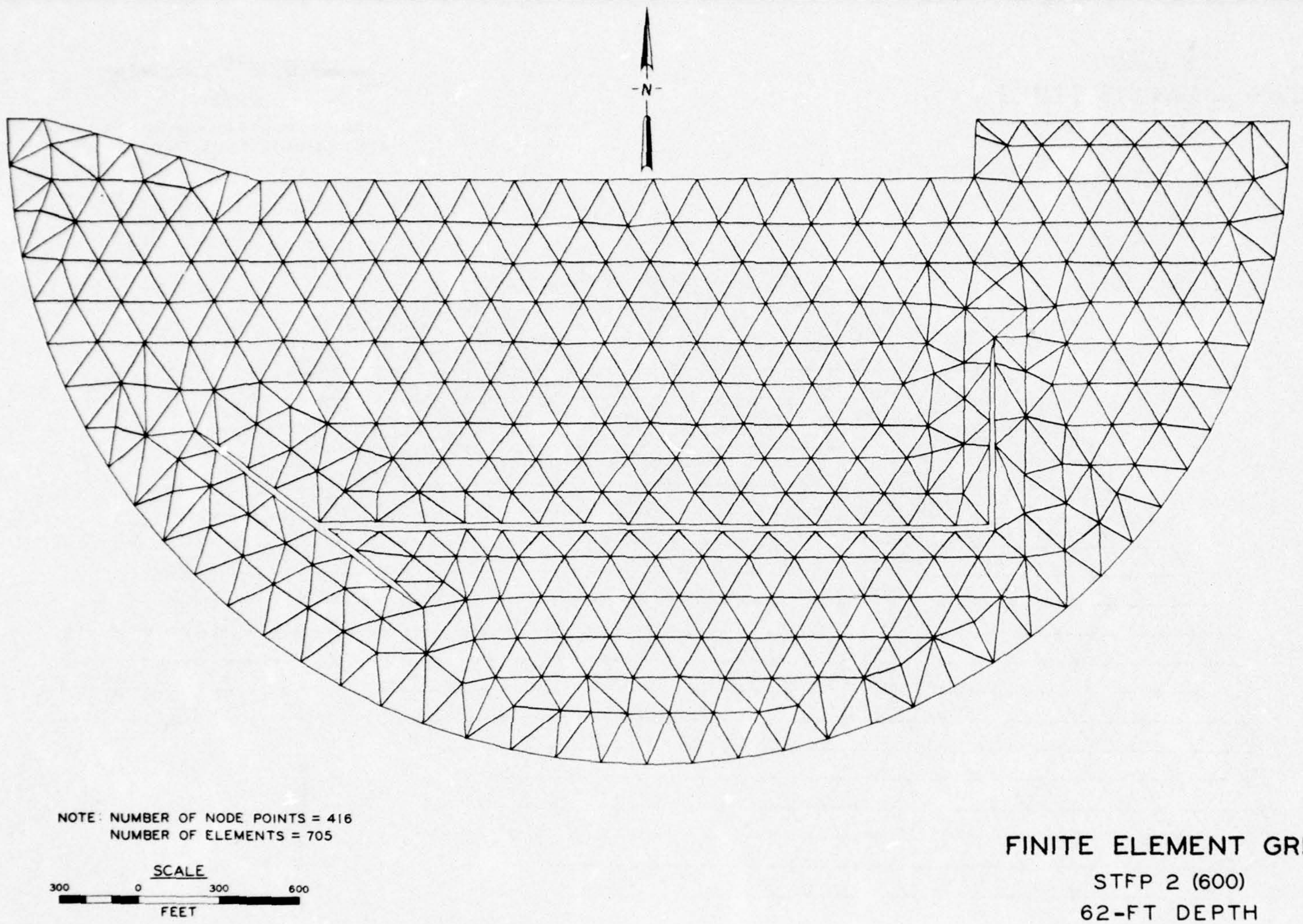
PLATE 3



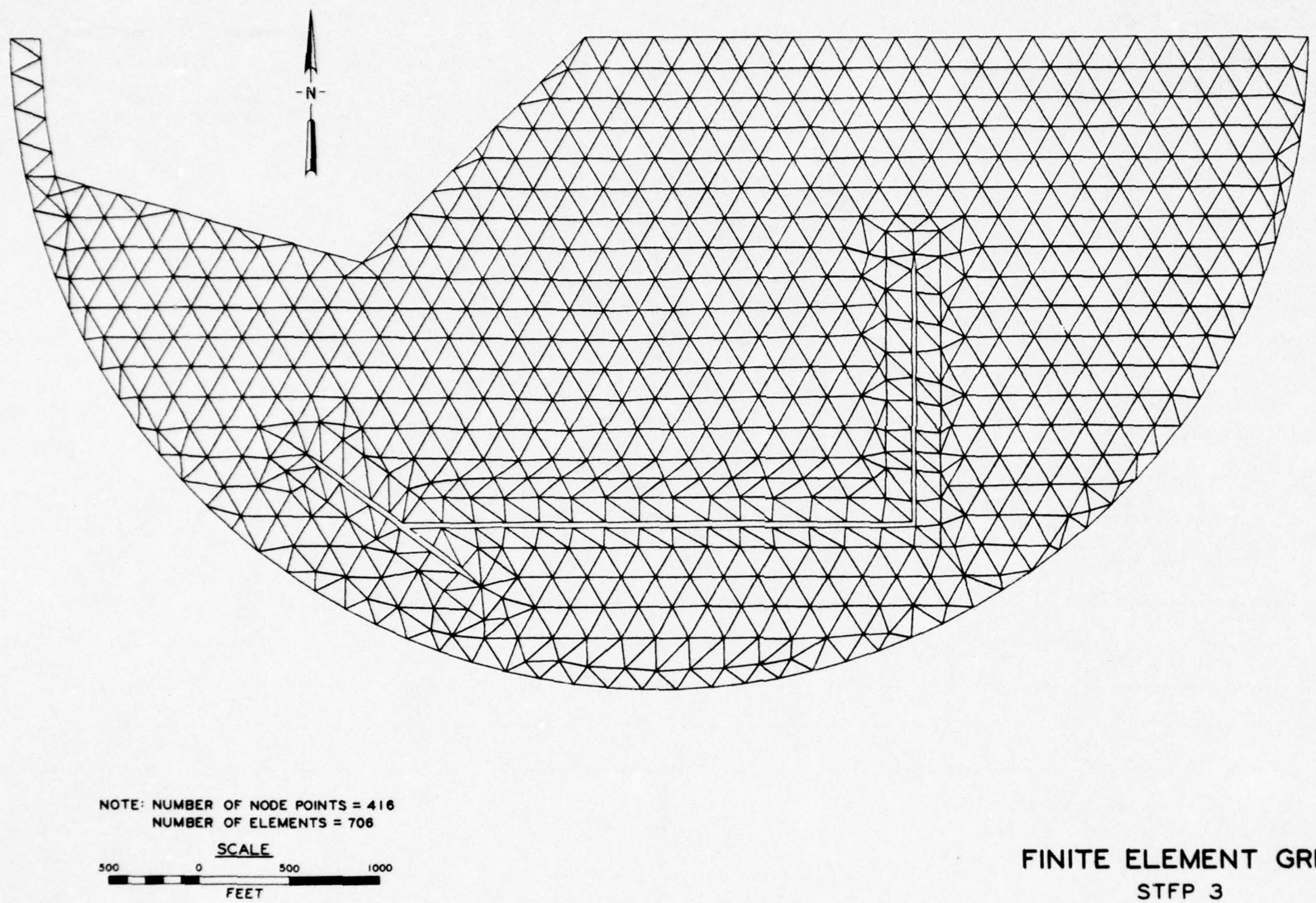
NOTE: NUMBER OF NODE POINTS = 416
NUMBER OF ELEMENTS = 705

FINITE ELEMENT GRID
STFP 2(300)
62-FT DEPTH

PLATE 4

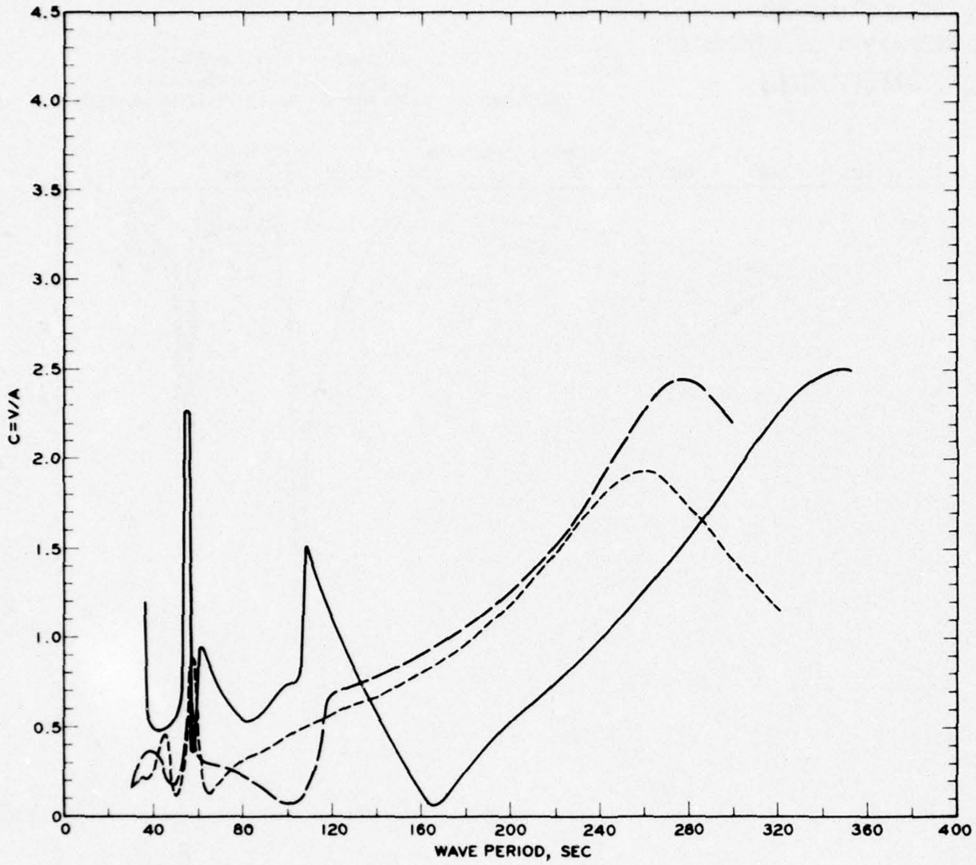


FINITE ELEMENT GRID
STFP 2 (600)
62-FT DEPTH



FINITE ELEMENT GRID
STFP 3

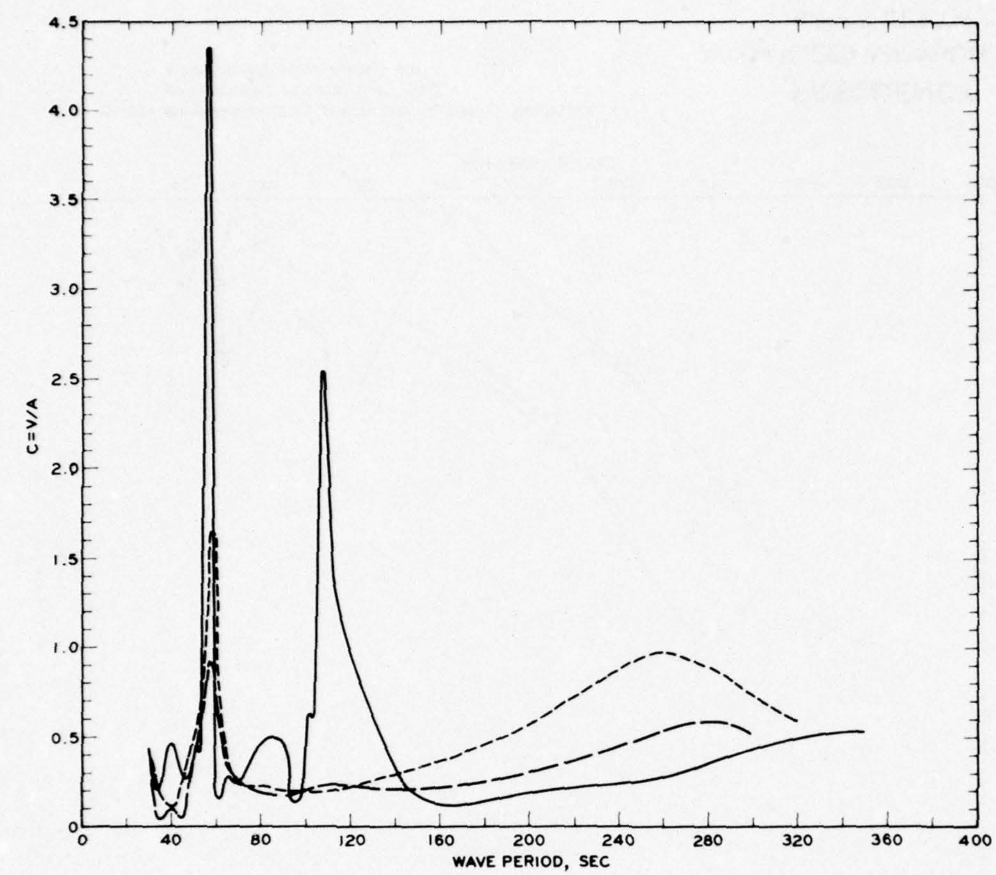
PLATE 6



LEGEND
- STFP 3
- STFP 2 (300)
- STFP 2 (600)

NOTE: C = NORMALIZED MAXIMUM CURRENT VELOCITY
V = CURRENT VELOCITY, FT/SEC
A = INCIDENT WAVE AMPLITUDE

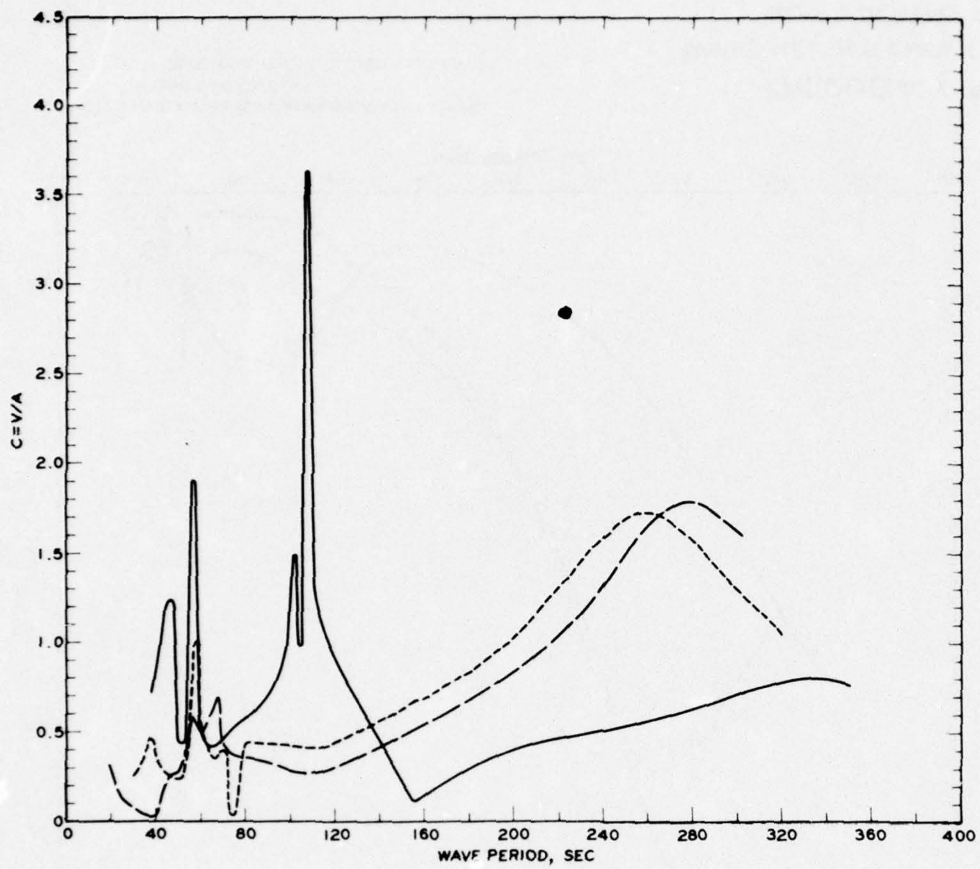
FREQUENCY RESPONSE
NORMALIZED MAXIMUM CURRENT VELOCITY
62-FT DEPTH, TERMINAL 1



LEGEND
——— STFP 3
— — STFP 2 (300)
----- STFP 2 (600)

NOTE: C = NORMALIZED MAXIMUM CURRENT VELOCITY
V = CURRENT VELOCITY, FT/SEC
A = INCIDENT WAVE AMPLITUDE

FREQUENCY RESPONSE
NORMALIZED MAXIMUM CURRENT VELOCITY
62-FT DEPTH, TERMINAL 2



LEGEND

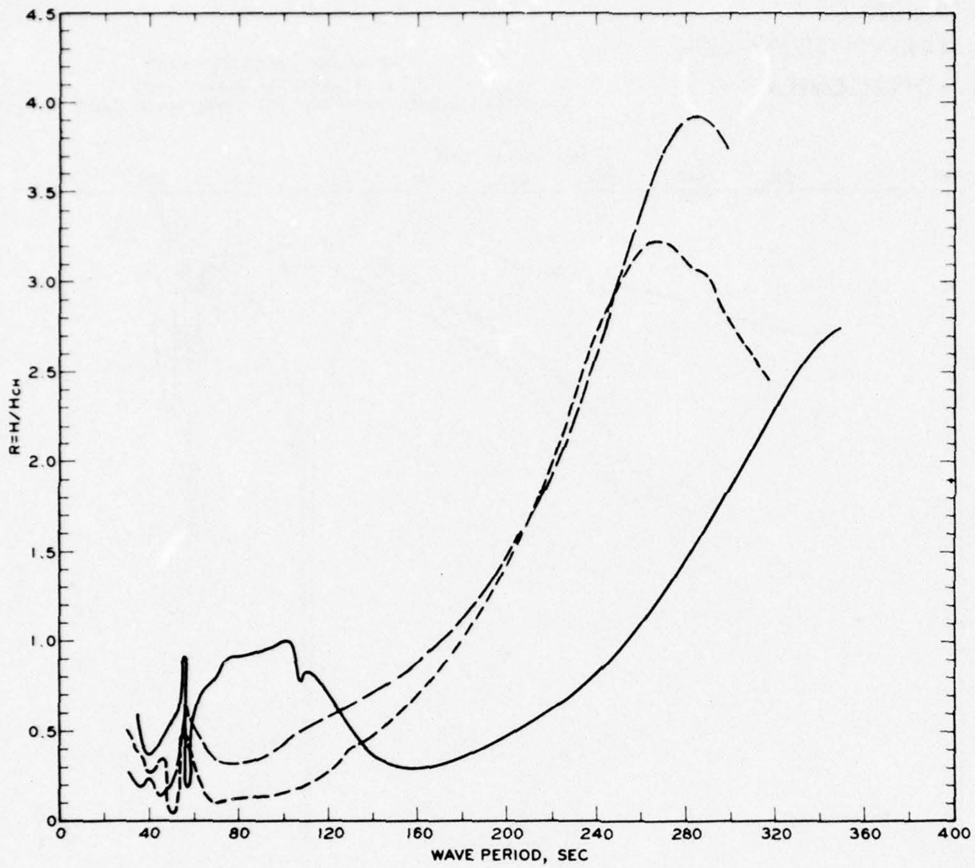
STFP 3

STFP 2 (300)

STFP 2 (600)

NOTE: C = NORMALIZED MAXIMUM CURRENT VELOCITY
V = CURRENT VELOCITY, FT/SEC
A = INCIDENT WAVE AMPLITUDE

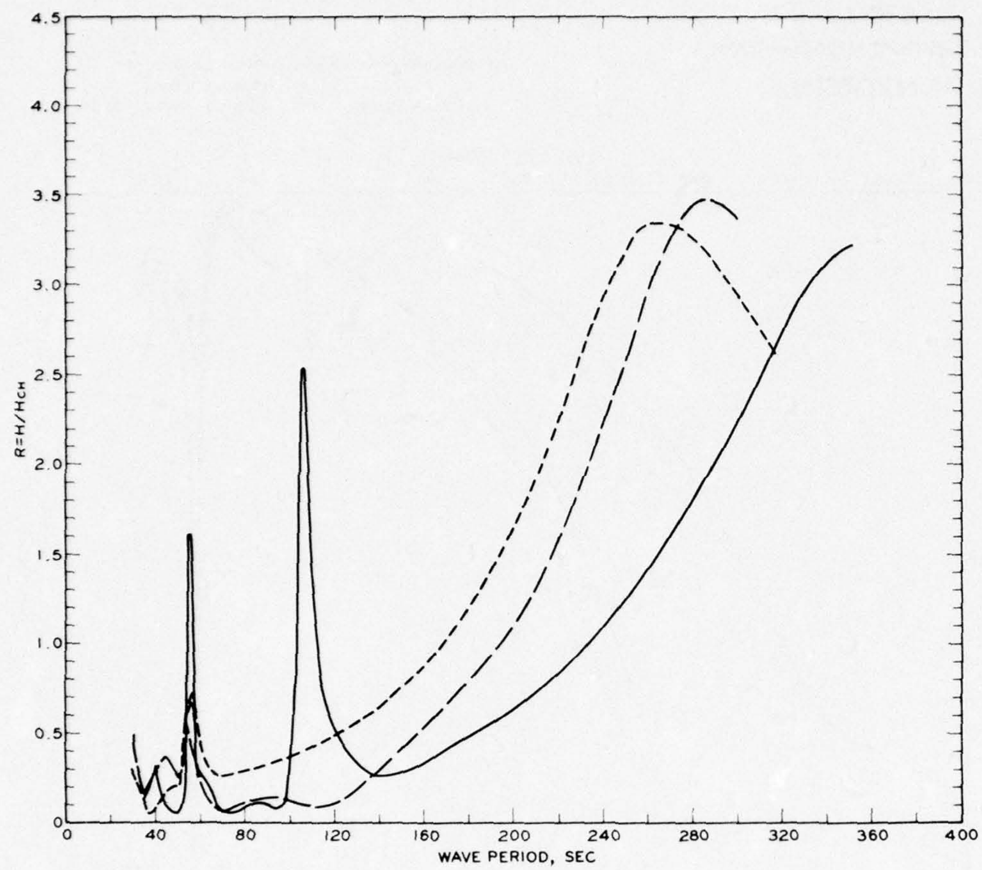
FREQUENCY RESPONSE
NORMALIZED MAXIMUM CURRENT VELOCITY
62-FT DEPTH, TERMINAL 3



LEGEND
- ——— STFP 3
- — — STFP 2 (300)
- - - - STFP 2 (600)

NOTE: R=WAVE HEIGHT AMPLIFICATION FACTOR
H=WAVE HEIGHT, FT
HCH=WAVE HEIGHT FOR CLOSED HARBOR, FT

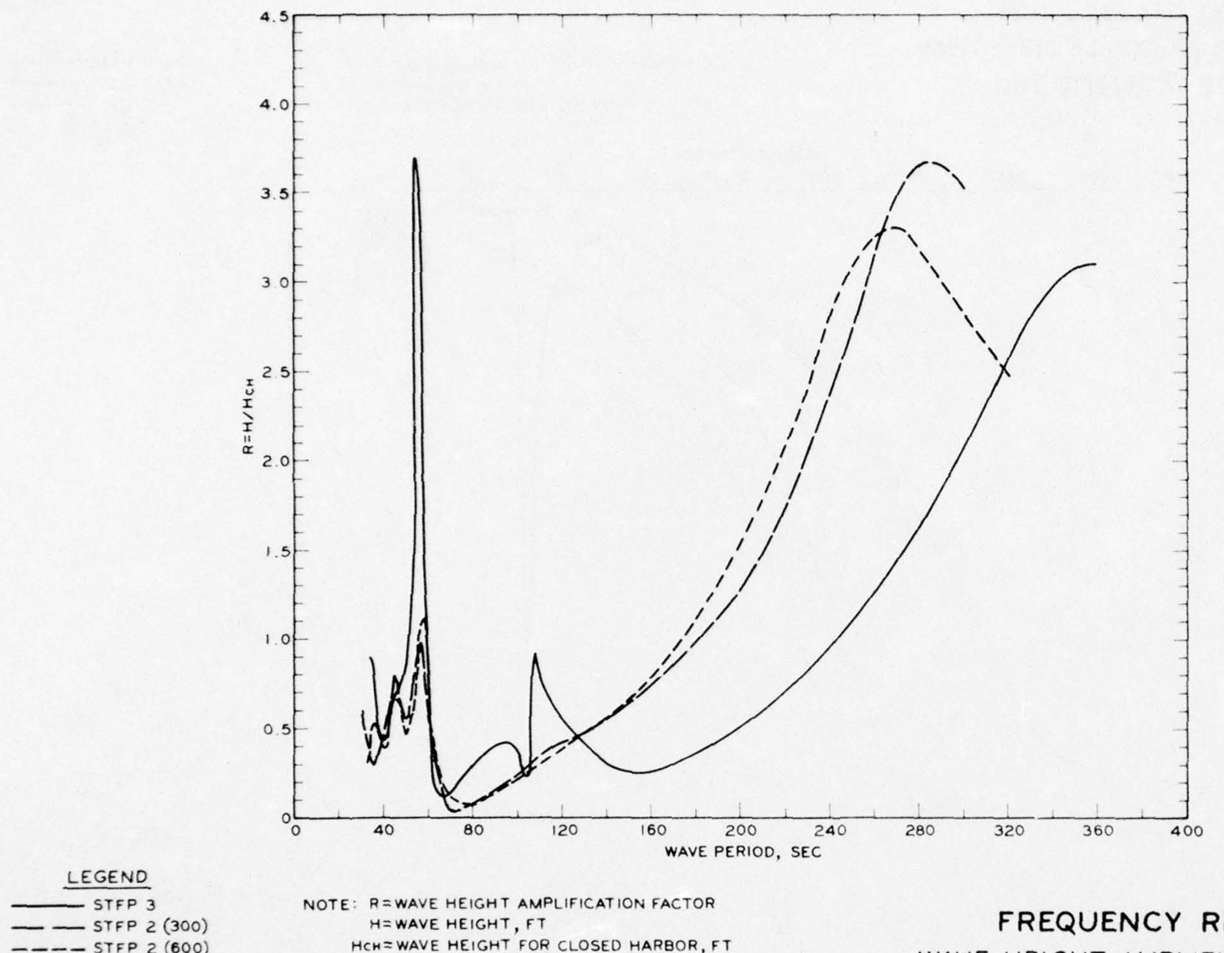
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION FACTOR
62-FT DEPTH, TERMINAL 1



LEGEND
STFP 3
STFP 2 (300)
STFP 2 (600)

NOTE: R=WAVE HEIGHT AMPLIFICATION FACTOR
H=WAVE HEIGHT, FT
HCH=WAVE HEIGHT FOR CLOSED HARBOR, FT

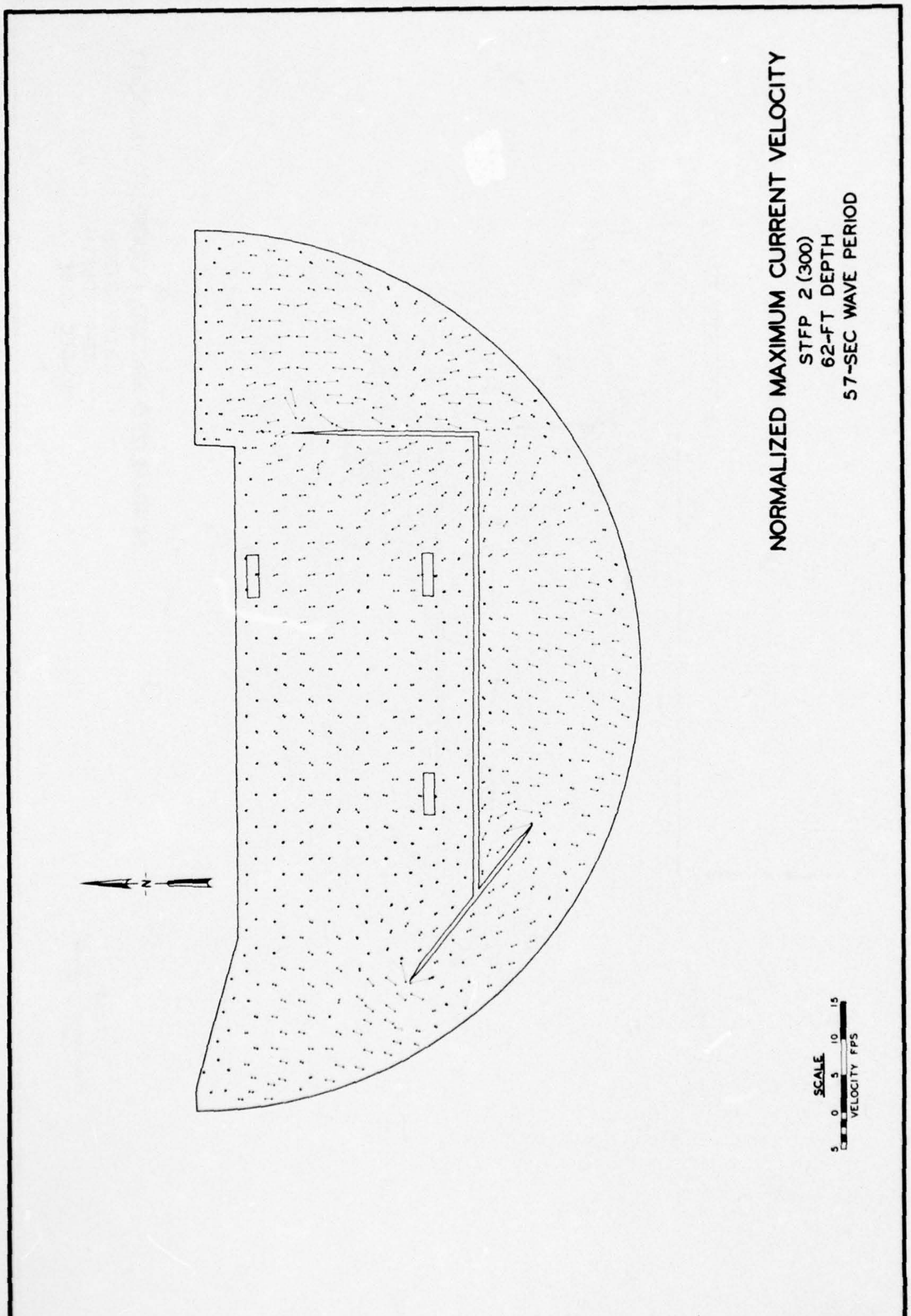
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION FACTOR
62-FT DEPTH, TERMINAL 2

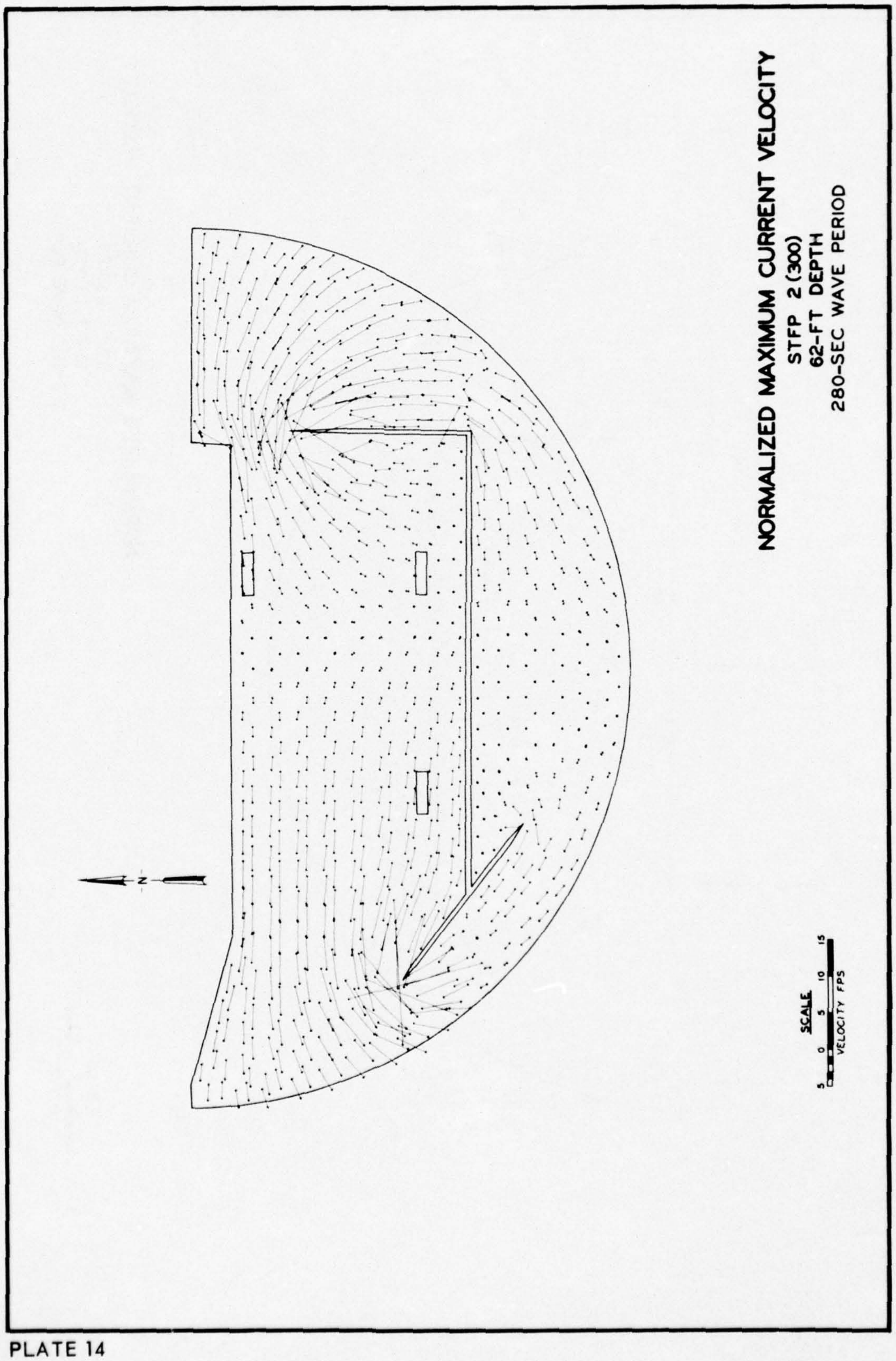


FREQUENCY RESPONSE

WAVE-HEIGHT AMPLIFICATION FACTOR

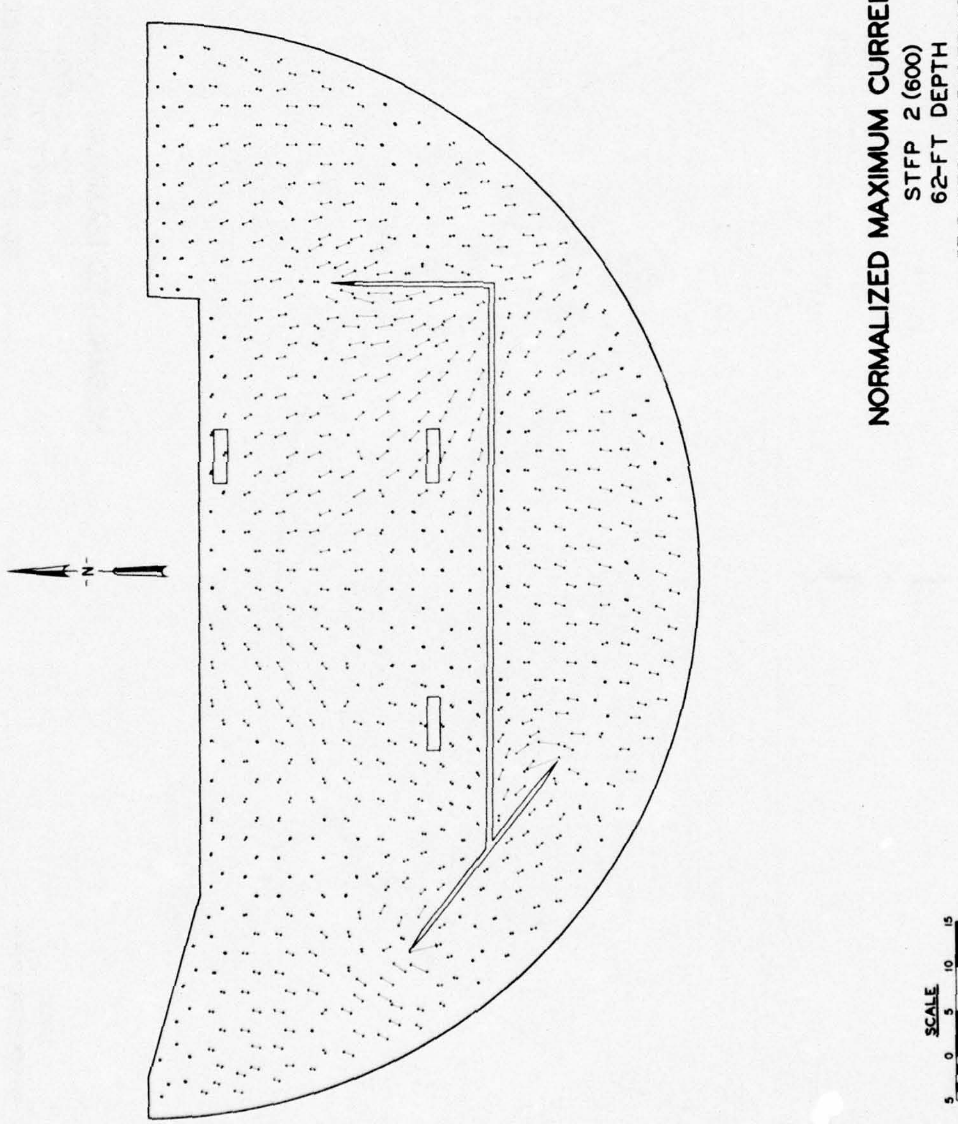
62-FT DEPTH, TERMINAL 3


NORMALIZED MAXIMUM CURRENT VELOCITY
STFP 2 (300)
62-FT DEPTH
57-SEC WAVE PERIOD
N
SCALE
5 0 5 10 15
VELOCITY FPS

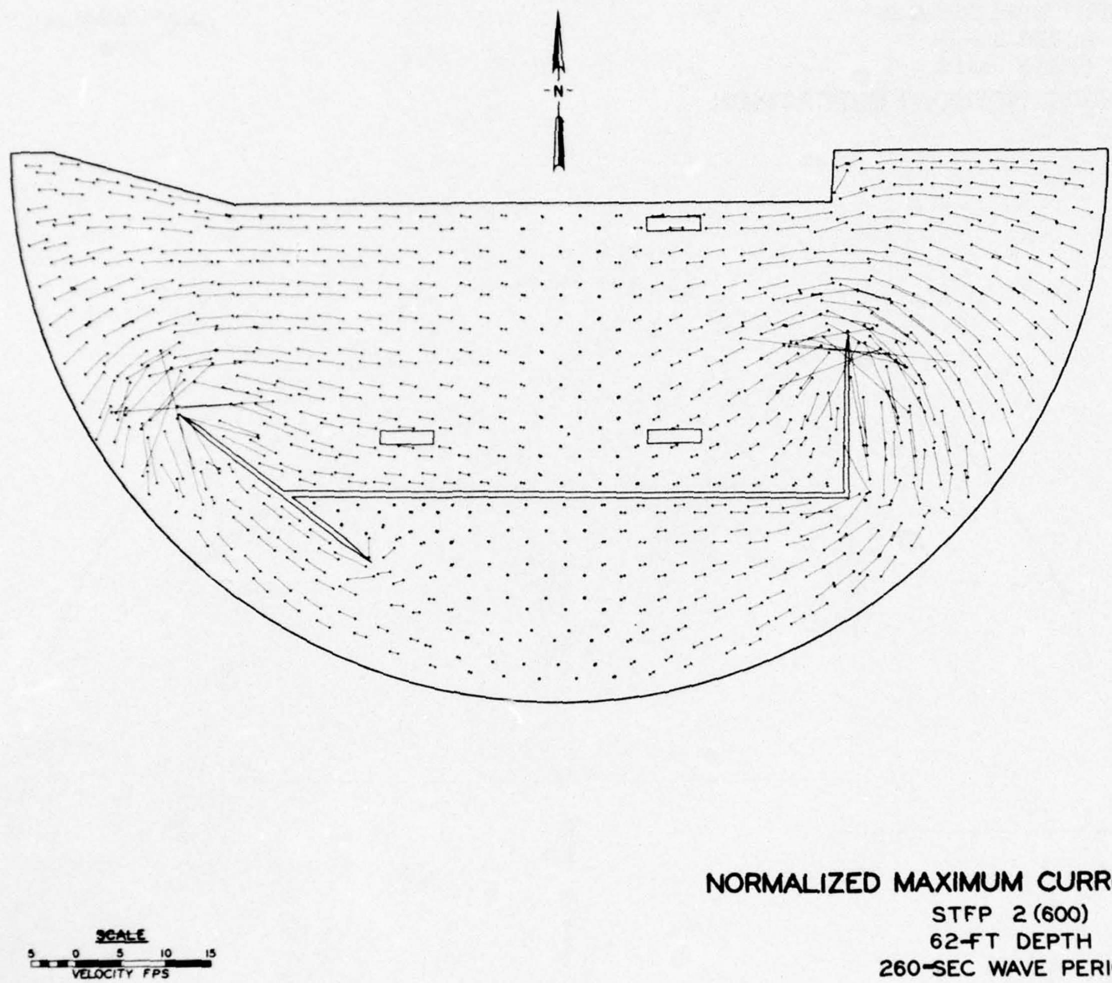


NORMALIZED MAXIMUM CURRENT VELOCITY
STFP 2 (300)
62-FT DEPTH
280-SEC WAVE PERIOD

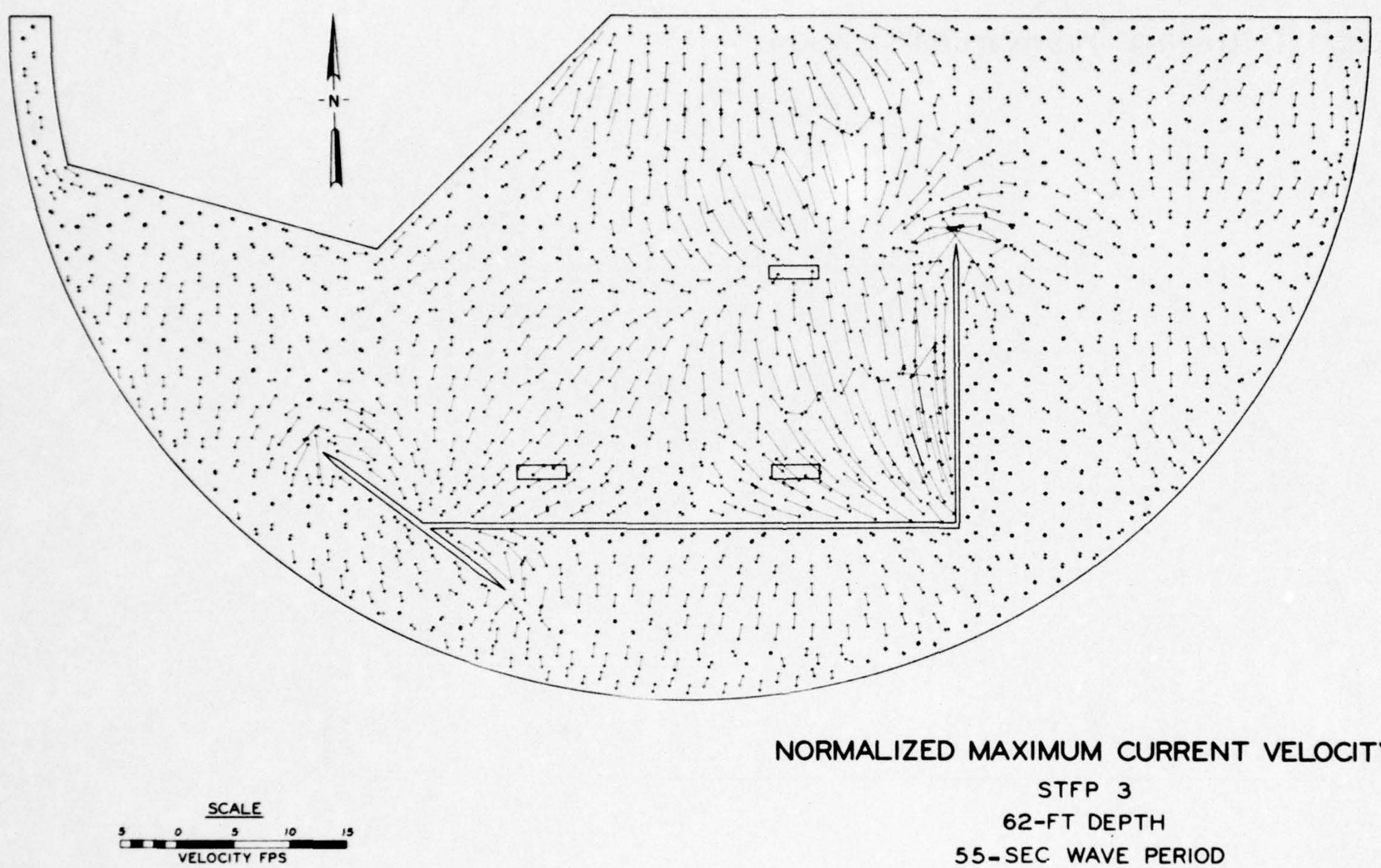
PLATE 14



NORMALIZED MAXIMUM CURRENT VELOCITY
STFP 2 (600)
62-FT DEPTH
57.5-SEC WAVE PERIOD



NORMALIZED MAXIMUM CURRENT VELOCITY
STFP 2 (600)
62-FT DEPTH
260-SEC WAVE PERIOD

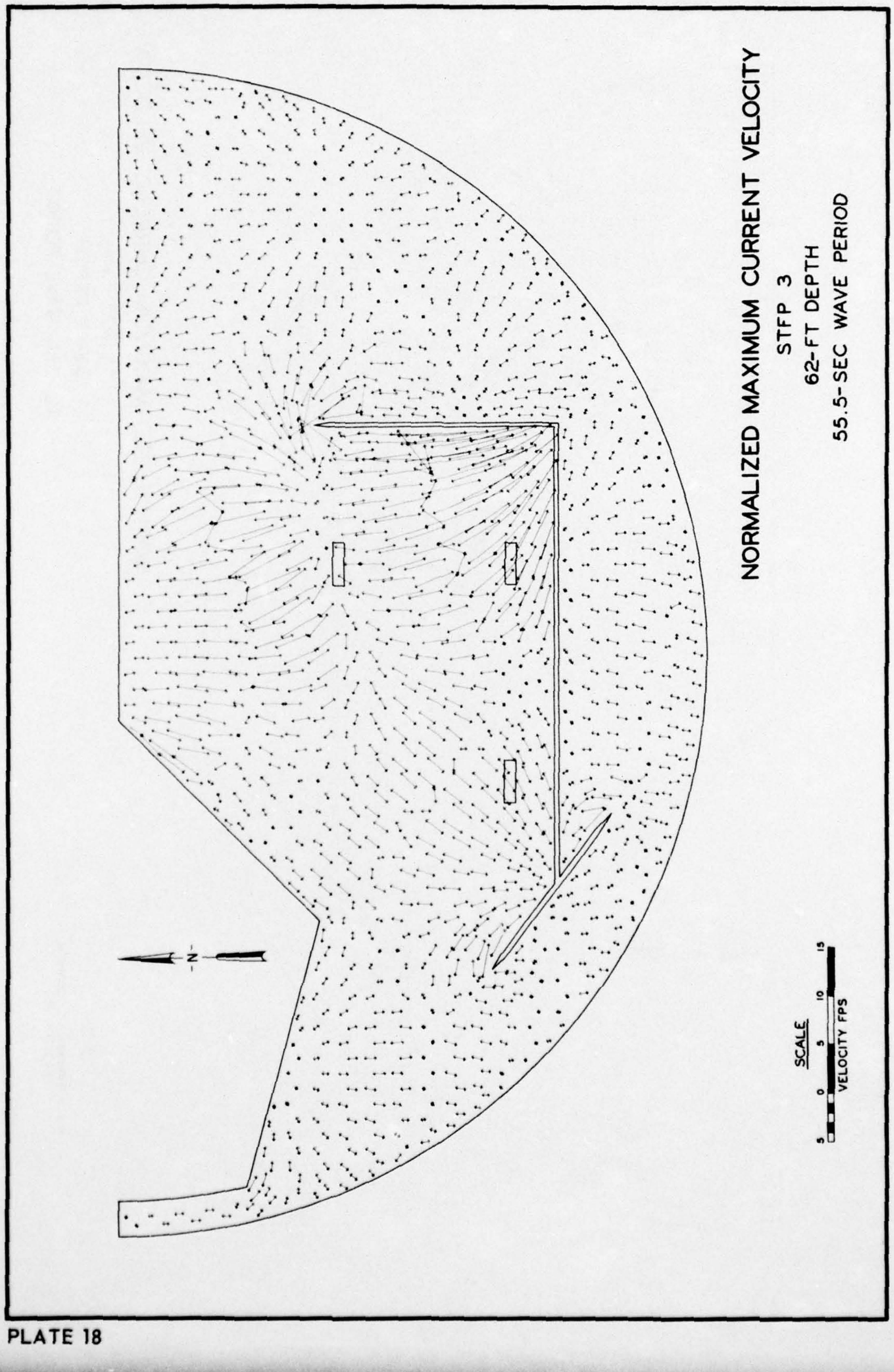


NORMALIZED MAXIMUM CURRENT VELOCITY

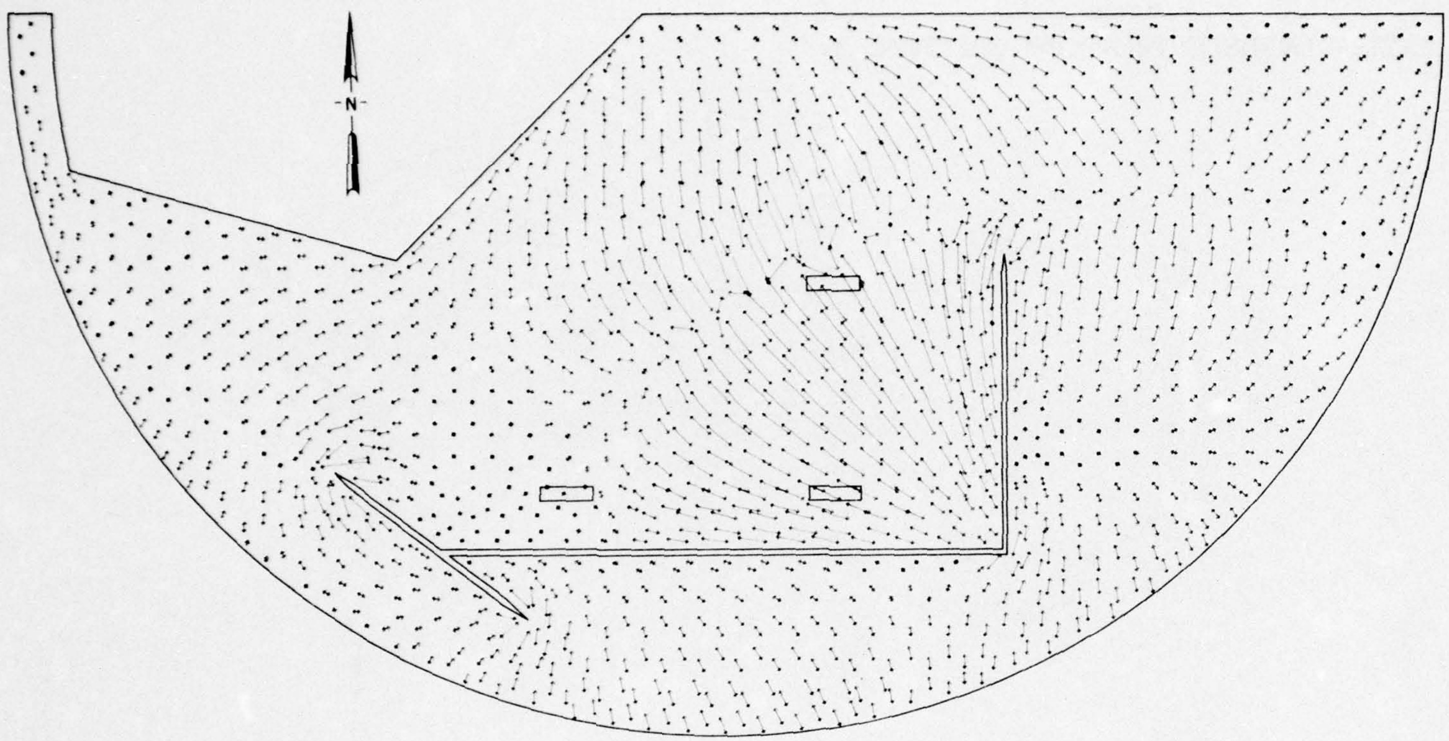
STFP 3

62-FT DEPTH

55-SEC WAVE PERIOD



NORMALIZED MAXIMUM CURRENT VELOCITY
STFP 3
62-FT DEPTH
55.5-SEC WAVE PERIOD
N
SCALE
5 0 5 10 15
VELOCITY FPS

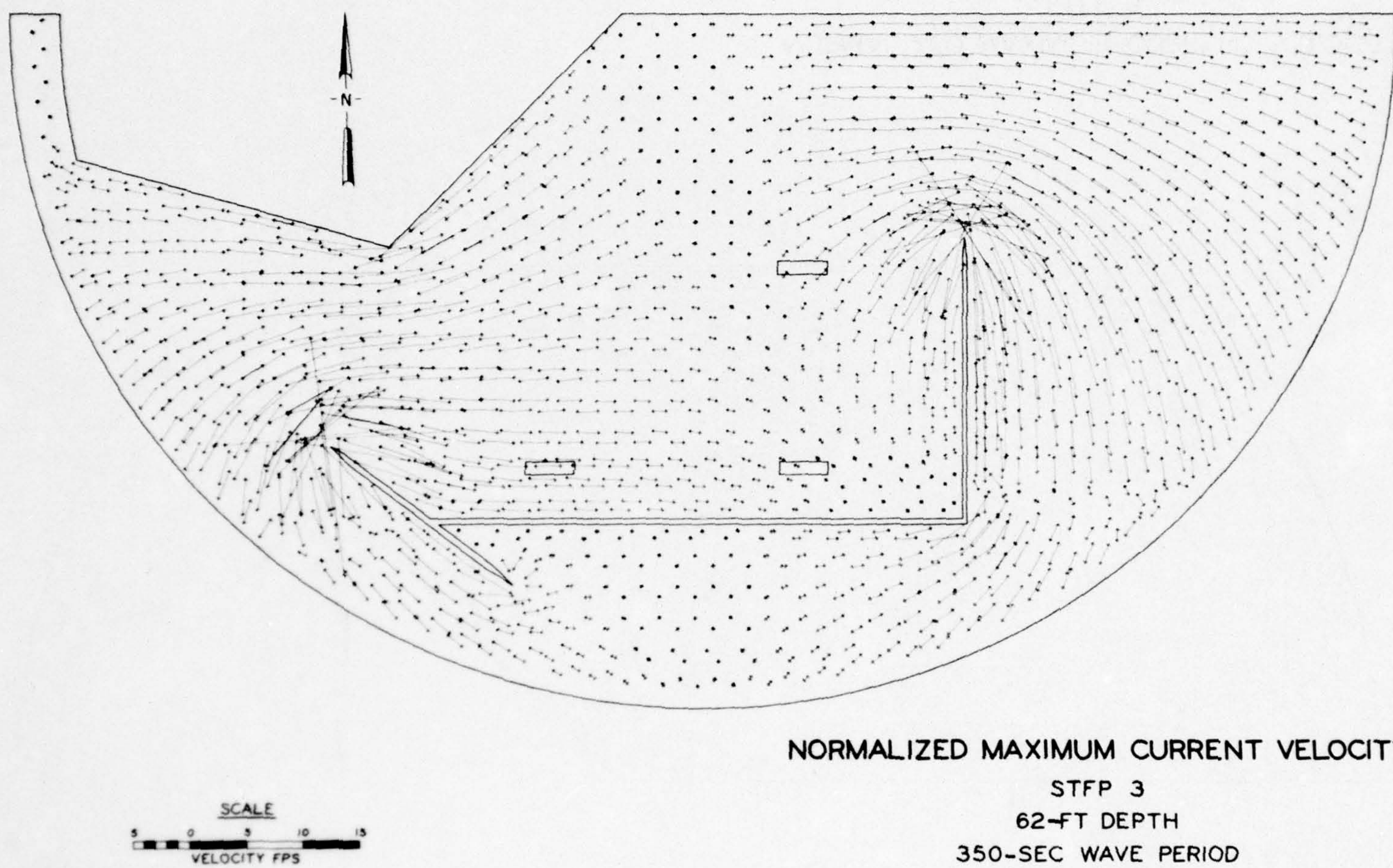


NORMALIZED MAXIMUM CURRENT VELOCITY

STFP 3

62-FT DEPTH

106-SEC WAVE PERIOD

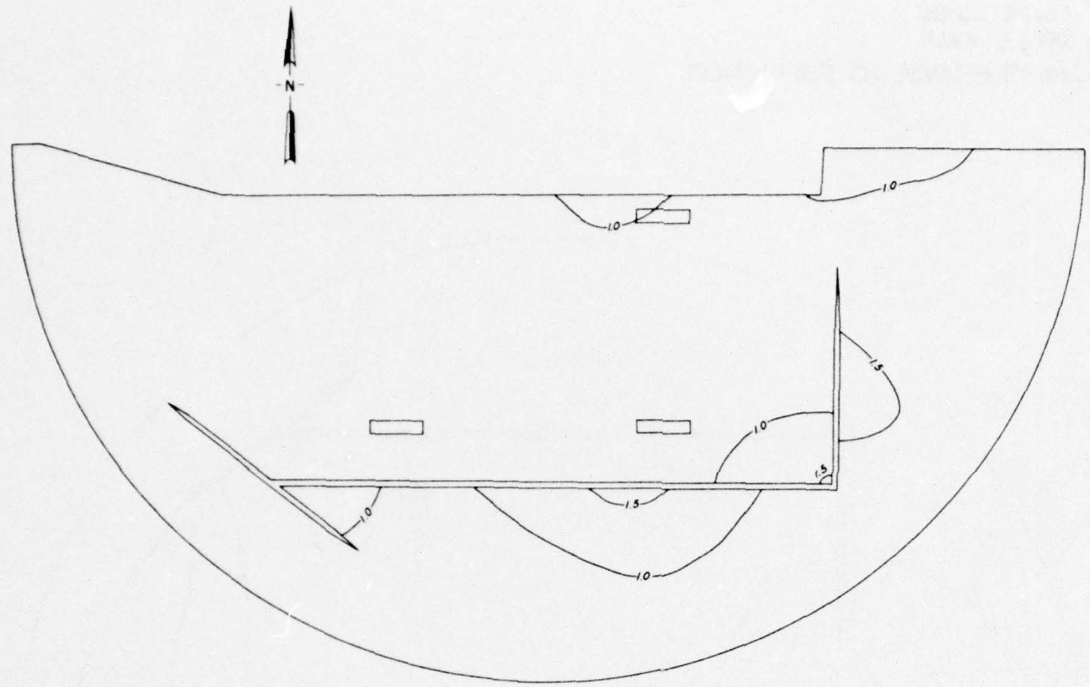


NORMALIZED MAXIMUM CURRENT VELOCITY

STFP 3

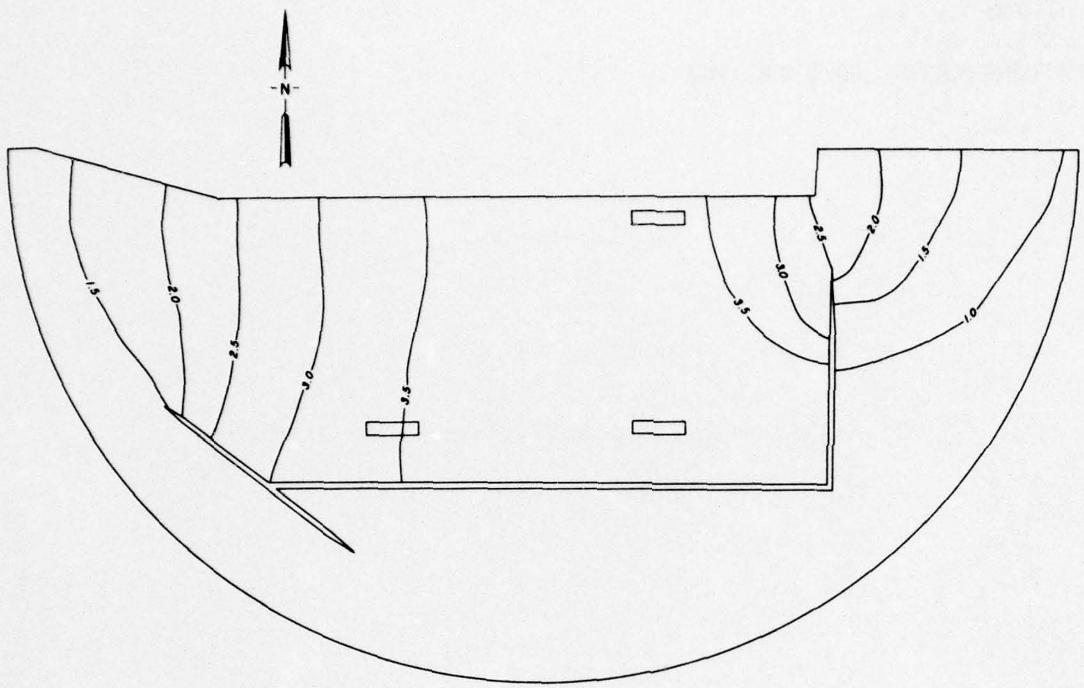
62-FT DEPTH

350-SEC WAVE PERIOD

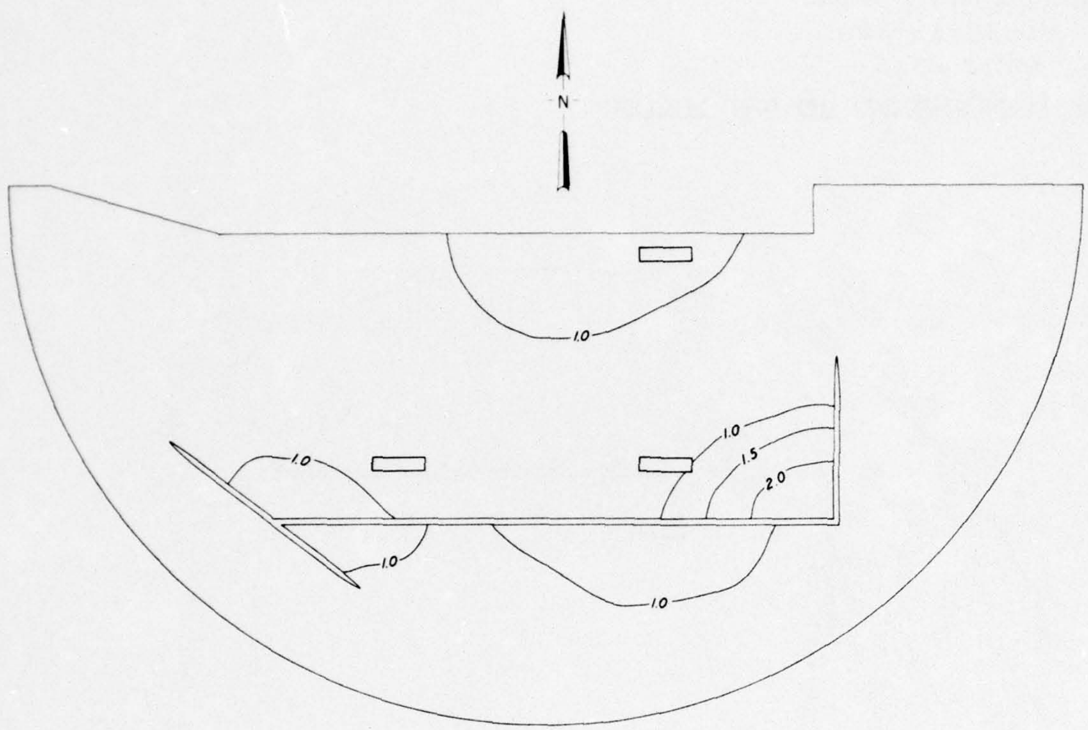


CONTOURS OF WAVE-HEIGHT AMPLIFICATION
STFP 2(300)
62-FT DEPTH
57-SEC WAVE PERIOD

PLATE 22



CONTOURS OF WAVE-HEIGHT AMPLIFICATION
STFP 2(300)
62-FT DEPTH
280-SEC WAVE PERIOD

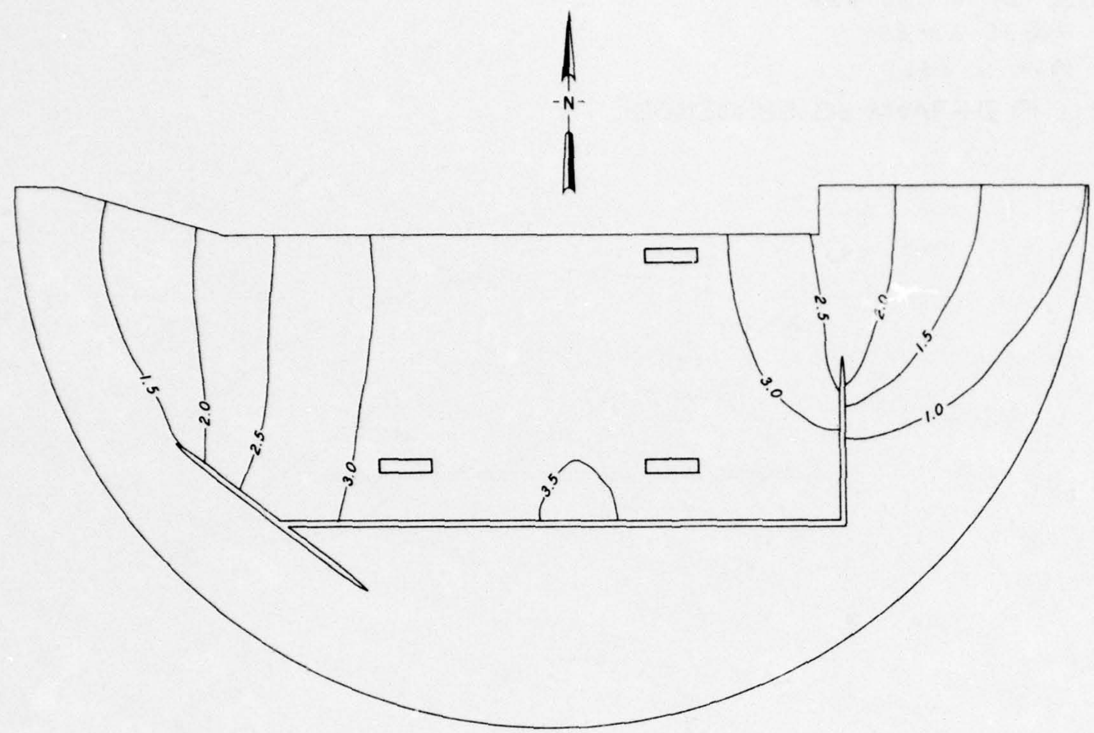


CONTOURS OF WAVE-HEIGHT AMPLIFICATION

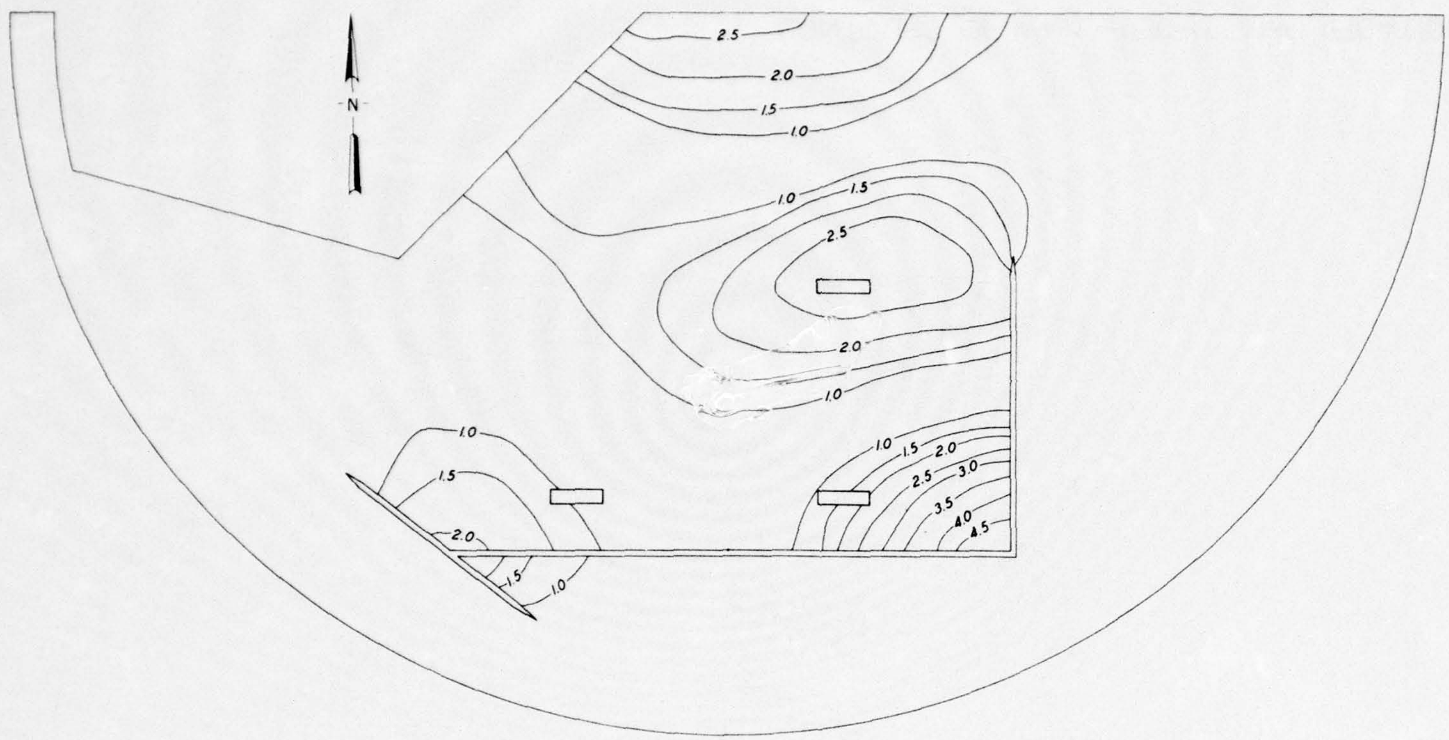
STFP 2 (600)

62-FT DEPTH

57.5-SEC WAVE PERIOD



CONTOURS OF WAVE-HEIGHT AMPLIFICATION
STFP 2 (600)
62-FT DEPTH
260-SEC WAVE PERIOD

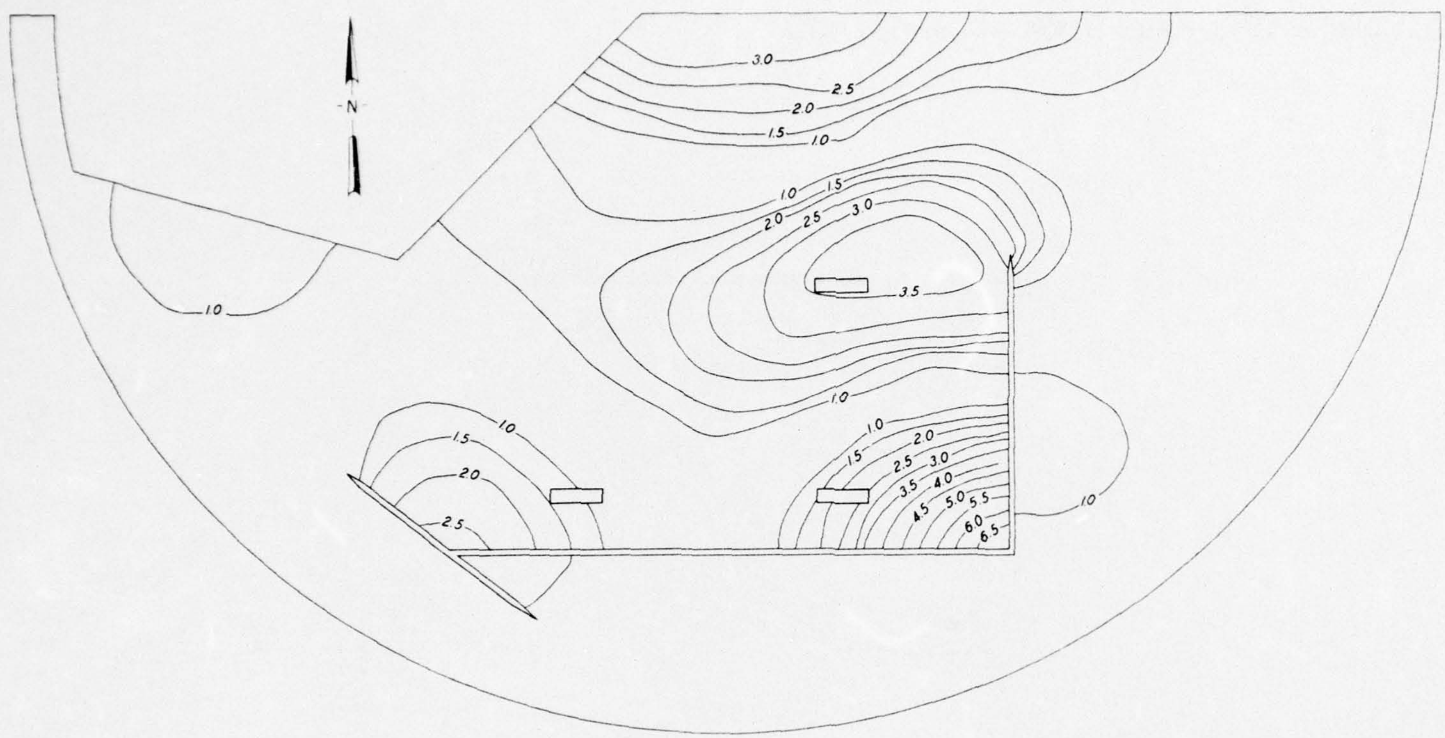


CONTOURS OF WAVE-HEIGHT AMPLIFICATION

STFP 3

62-FT DEPTH

55-SEC WAVE PERIOD

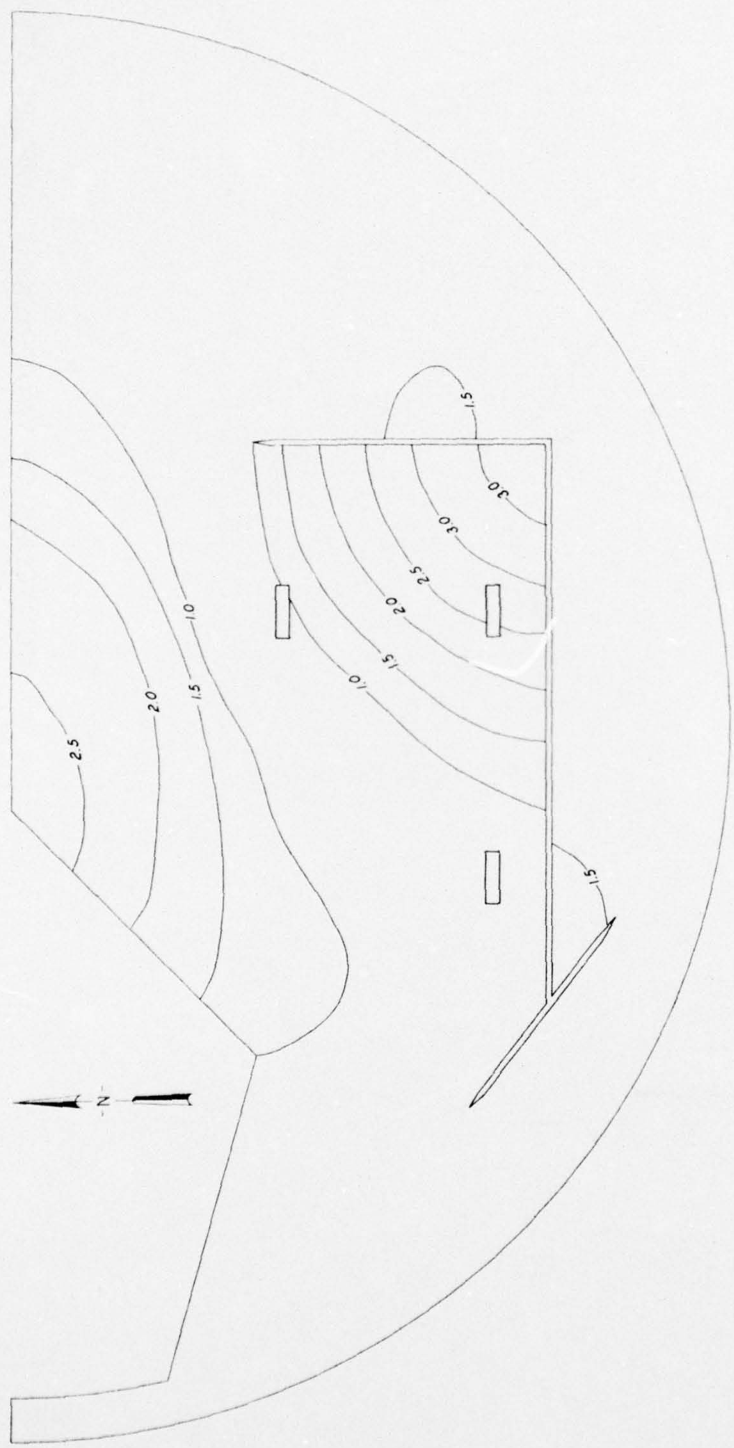


CONTOURS OF WAVE-HEIGHT AMPLIFICATION

STFP 3

62-FT DEPTH

55.5-SEC WAVE PERIOD



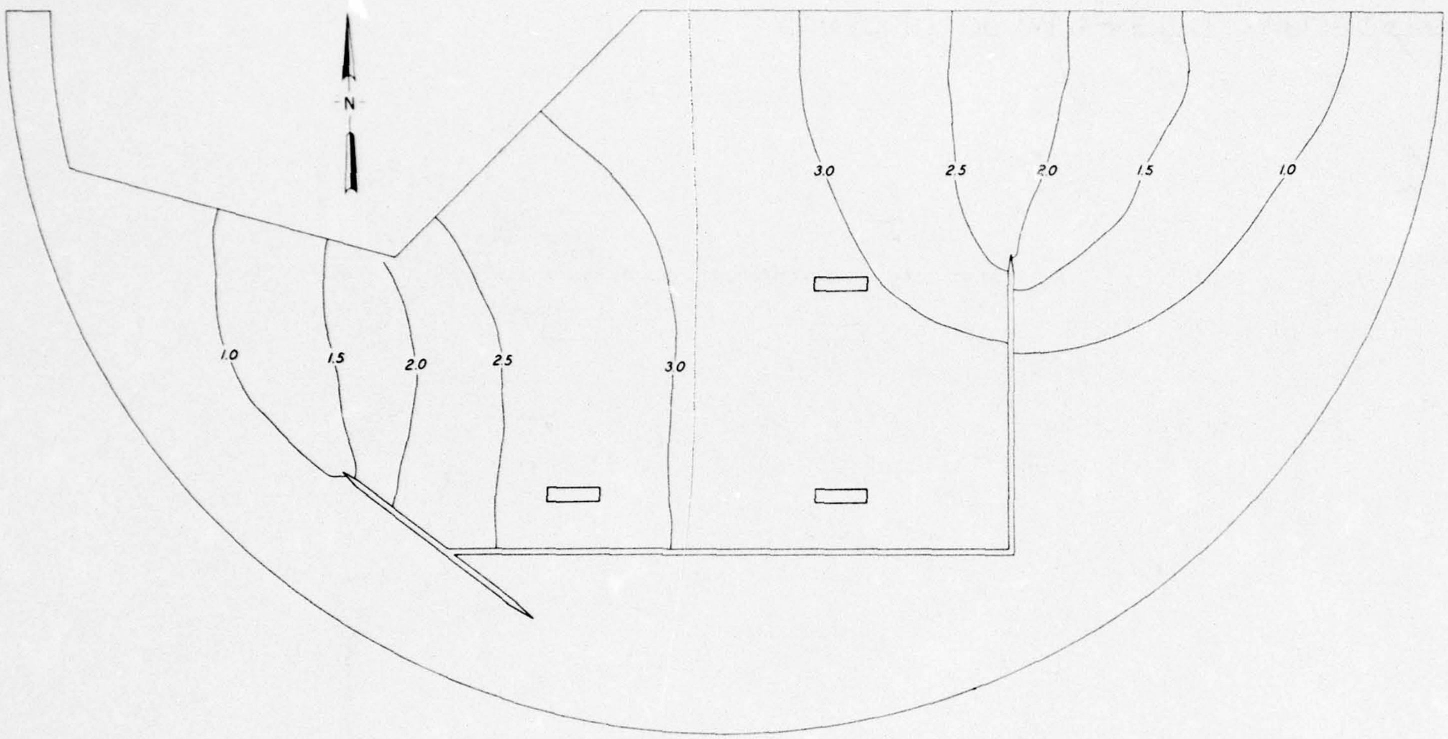
CONTOURS OF WAVE-HEIGHT AMPLIFICATION

STFP 3

62-FT DEPTH

106-SEC WAVE PERIOD

PLATE 27



CONTOURS OF WAVE-HEIGHT AMPLIFICATION

STFP 3

62-FT DEPTH

350-SEC WAVE PERIOD

APPENDIX A: NOTATION

a	Boundary of region A
A	Area of region inside a harbor
g	Acceleration due to gravity, 32.2 ft/sec^2
h	Water depth, ft
H_n	Hankel function of the first kind of order n
i	Imaginary number
k	Wave number, ft^{-1}
n	Integer
n_a	Unit vector normal to boundary a
r	Spherical coordinate, ft
t	Time, sec
u	Velocity in x-direction, ft/sec
v	Velocity in y-direction, ft/sec
w	Angular velocity, radians/sec
x	Cartesian coordinate, ft
y	Cartesian coordinate, ft
α_n	Unknown coefficient
∇	Gradient, ft^{-1}
η	Wave amplitude, ft
θ	Spherical coordinate, degrees
ϕ	Total velocity potential, ft^2/sec
ϕ_a	Total velocity potential evaluated on boundary a, ft^2/sec
ϕ_I	Incident velocity potential, ft^2/sec
ϕ_R	Far field velocity potential, ft^2/sec
ϕ_s	Scattered velocity potential, ft^2/sec

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Houston, James R
Long Beach Harbor numerical analysis of harbor oscillations; Report 2: Alternate plans for Pier J completion and tanker terminal project, by James R. Houston. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.
1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper H-76-20, Report 2)
Prepared for Port of Long Beach, Long Beach California.

1. Harbor oscillations. 2. Long Beach Harbor. 3. Numerical analysis. 4. Piers (Docks). 5. Tanker terminals. I. Port of Long Beach. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper H-76-20, Report 2)
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